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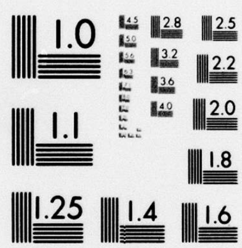

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NEW COEFFICIENTS FOR THE SWANSON PPC MODEL AS UTILIZED BY OMEGA AT 10.2 kHz.

A.I. TOLSTOY

OCTOBER 1976

Prepared by

DEPARTMENT OF TRANSPORTATION

United States Coast Guard
OMEGA Navigation System
Operations Detail
Navigational Science Branch

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16. Abstract

New least squares regression coefficients for the Swanson PPC model at 10.2 kHz have been computed. The data and its deficiencies are discussed. Significant improvement in the accuracy of predictions for station D in the Mediterranean region has been obtained. Indications are that further research into the geomagnetic models is needed.

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ABSTRACT

New least squares regression coefficients for the Swanson PPC model at 10.2 kHz have been computed. The data and its deficiencies are discussed. Significant improvement in the accuracy of predictions for station D in the Mediterranean region has been obtained. Indications are that further research into the geomagnetic models is needed.

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"New Coefficients for the Swanson PPC Model as Utilized by Omega at 10.2 kHz"

A. I. Tolstoy

I. Introduction

The Swanson phase propagation correction (PPC) model is a computational scheme which attempts to semi-empirically model phase variations $\Delta\phi$ from the nominal as a function of the specific diurnal and geophysical conditions encountered along any given path. The model is comprised of thirteen geophysical submodels which interact in linear combination with each other and which are modified by a solar zenith angle model which accounts for the observed diurnal effects. That is,

$$\Delta\phi_T(P,t_o) = \sum_{n=1}^{N} \sum_{i=1}^{13} (a_i + b_i f_T(X_n)) H^T_{i,n}(P) ,$$

where P = point on surface of earth,

t_o = specific hour of interest,

$\Delta\phi_T(P,t_o)$ = predicted phase variation from nominal of signal from transmitter T to point P at time t_o,

a_i, b_i = linear coefficients for the i^{th} geophysical model,

$H^T_{i,n}$ (P) = geophysical model value at n^{th} path segment from transmitter T to point P,

X_n = solar zenith angle at n^{th} path segment,

$f_T(\cdot)$ = diurnal function which also accounts for abrupt changes at sunrise and sunset,

N = total number of path segments (1 path segment is .01 radians in length).

The geophysical models themselves account for geomagnetic field effects, polar cap and auroral zone effects, ground conductivity effects and excitation behavior. For a thorough discussion of these models and their development see references 1-4. It should be emphasized that the Swanson PPC model describes only the behavior of a single, dominant mode signal.

The linear coefficients of the Swanson model are determined by an unweighted least squares regression fit of the model to a data base of observed phase values (1). The coefficients presently in use were determined in 1971 (2), and this paper proposes a new set of coefficients which were generated from a more current data base at 10.2 kHz. In general, the new coefficients are very similar to the old, but it is worth noting that the new coefficients appear to differ greatly from the old coefficients in their fifth through tenth values. These values correspond to the midpath geomagnetic models which were determined by a Fourier fit to theoretical data, and as such their combined rather than their individual effects are what influence prediction. This resultant effect with the new coefficients does not differ greatly from the old resultant effect. However, the new twelfth day coefficient is very different from the old value. This coefficient corresponds to the ground conductivity effects upon excitation behavior. It is not understood why this value is so different from its previous value.

1. See reference 5 for further information concerning the application of the least squares estimation technique.
2. See appendix A for the coefficient values.

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II. Data Base

The reliability and accuracy of any data base is absolutely critical and cannot be over-emphasized. The most time-consuming portion of this entire study was the intense scrutinizing required before data could be accepted for the final processing. There is, of course, always the danger of over-refining a data base by rejecting valid data which simply may not fit one's scheme of things. Hopefully, this has been avoided by eliminating only that data which was severely erratic or known to be in error. A list of the events (3) which were judgementally deleted is presented in appendix C. In addition, the current data base is comprised of events which meet the following criteria:

* The events must have occurred after April, 1970 (this eliminates very old signal data which existed prior to active system synchronization with UTC) and also this choice minimized the eleven year solar cycle effect while maximizing the data base;
* The events must not involve station Forestport, N.Y. (this station has not been operational since Fall, 1972);
* At least two months of usable data must exist for each fixed monitor site and pair of transmitters (this criterion should eliminate data whose stability is unknown);
* Events with possible modal interference must be deleted. This criterion is more involved than the others and necessitates dividing the data base into two parts, i.e. a day data base and a night data base. The day data base consists of all events meeting the above criteria minus those events observed within the near field of a transmitting station, i.e. those sites involving LOP x within one megameter of transmitter x. The night data base consists of the day data base minus those events which lie in a predicted night modal interference zone for a given transmitter signal (see reference 6) and
  1. have fewer than 5 months of data, or
  2. have a sample standard deviation for received phase which is greater than 5 cecs.

This criterion resulted in the elimination at night of the following combinations:

Monitor Site	Transmitter
Belem, Brazil	Trinidad
Sabana Seca, Puerto Rico	Trinidad
Orote Pt., Guam	Hawaii
Tsushima, Japan	Hawaii
Spitzbergen, Norway	Norway
Rome, N.Y.	North Dakota
Bermuda	North Dakota
Norfolk, VA.	North Dakota
Makapuu, Hawaii (Long path interference)	Trinidad

Finally, the transmitting station monitors all report data involving their near-field transmitter. The path from this transmitter to the site is such a short path that the signal behavior is not accurately described by the models employed herein. For these cases, the data was reprocessed in order to eliminate the offending station. The final data base is described in detail in appendix B. It should be noted that the data base contains no information on transmitters in the southern hemisphere, and only two of the monitor sites (RIO-D and TANAN) lie south of the geomagnetic equator.

3. An event is defined here to be one month of phase difference data (the difference of the received phases of two transmitters) observed at a given monitor site.

III. Results

Overall, for the current data base the new coefficients show significant improvement in the accuracy of their predictions over the old coefficients.

The behavior of each given set of coefficients has been judged by examining the magnitude of the predicted residual errors which they produce. These errors are computed by subtracting a day or night predicted phase difference value from the average day or night phase difference value observed in the data base for a fixed monitor site and LOP pair. The predicted errors will generally be within a few centicycles (cecs) of the errors actually observed. These variations will occur because of the instabilities in the observed data which are caused by random changes in the ionosphere, solar variations, noise (lightning induced), modeling difficulties for paths in solar transition (sunrise and sunset), and receiver errors.

Looking at tables 1-2 we observe that the total root-mean-square (RMS) errors have been reduced from 8.864 cecs (fitting the present data base with the old coefficients which were derived from an old data base) to 5.188 cecs during day hours (4) and from 8.761 cecs to 5.400 cecs at night. This represents a 42% improvement for day and a 39% improvement for night predictions. Examining the individual pathpair errors we see that only in a few cases do these errors appear to significantly increase in the new fit (5).

These 6 cases are presented in table 3(6). We note that in three of these a poor day (or night) fit is counteracted by an improved night (or day) fit! To be thorough we examined 24 hour plots of the observed data values versus the predicted data values over a typical 30 day period (7). We concluded that in only one case (see figures 1-12) did the complete 24 hour fit deteriorate significantly (8). This one case is SPITS AC where only 4 months of data were used and this data was fairly old (early 1971).

On the other hand, many of the data fits improved dramatically. Specifically, such critical LOP's as Sardinia AD, DG; Farnborough, England AD; and Orote Point, Guam DH showed improvements on the order of 10 cecs (not an RMS value) or more (see figures 12-20). Thus, it becomes apparent that the new coefficients, while not supplying perfect fits everywhere, can reduce many of the gross inaccuracies prevailing in the northern hemisphere with the coefficients currently in use. Moreover, in only one such case did the new coefficients actually produce seriously worse data fits.

It should be again emphasized that the generating data base contained only phase differenced data and only for transmitters in the northern hemisphere. Attempts have been made to evaluate single station predictions for northern, southern and inter-hemispheric paths for the new coefficients, and the results have been quite surprising. In particular, recent single station paths which lie totally within the northern hemisphere are predicted quite well by the new coefficients (see appendix D). Also, available non-computerized data (for August 1976) for the paths from station E to station F and from station F to station E are fit quite well (within 6 cecs) by the new coefficients. However, when examining such inter-hemispheric paths as station A to station E, station D to station F, station G to station

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4. Day (night) hours are those GMT hours during which both transmitting paths to a monitor site are totally illuminated (in darkness).
5. A fit is defined to be significantly worse if a previously good fit (less that 6.5 cecs error) now shows a bias (error is greater than or equal to 6.5 cecs) and the change in error is greater than 3 cecs.
6. A = Norway; B = Liberia; C = Hawaii; D = North Dakota; E = La Reunion; F = Argentina; G = Trinidad; H = Japan. See appendix E for coordinates.
7. A "typical" month of data was decided to be one where the day and night phase difference values were close to the overall mean day and night phase difference values (for that site and LOP).
8. A 24 hour fit is defined to be significantly worse if the new RMS error (for 24 hours) is more than 3 cecs greater than the old RMS error (for 24 hours).

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SITE	LOP	WEIGHT	DAY STATISTICS OBSERVED	NEW COEFFICIENTS PREDICTED	NEW COEFFICIENTS ERROR	OLD COEFFICIENTS PREDICTED	OLD COEFFICIENTS ERROR
BERMU	AC	1.00	24.5	17.5	6.9	28.1	-3.6
BERMU	AG	1.00	-56.0	-57.8	1.8	-45.9	-10.1
NELC.	CG	1.00	23.5	26.1	-2.6	22.1	1.3
ROME.	AC	1.00	28.0	24.5	3.6	27.1	1.0
ROME.	AG	1.00	-21.5	-25.7	4.2	-20.2	-1.3
ROME.	CG	1.00	-47.8	-50.2	2.3	-47.2	-0.6
SARDI	AG	1.00	62.8	56.7	6.1	53.1	9.6
WALES	AC	1.00	-6.3	-10.0	3.7	-1.0	-5.2
MIAMI	CG	1.00	-59.0	-61.1	2.1	-61.2	2.2
BERMU	CG	1.00	-74.7	-75.4	0.6	-74.0	-0.8
CORAL	AC	0.	39.2	36.1	3.1	39.1	0.1
FARNB	AG	1.00	66.4	65.8	0.5	61.9	4.5
GRAND	CG	1.00	38.2	33.6	4.6	25.5	12.7
SPITS	AG	1.00	80.7	86.4	-5.7	81.0	-0.3
SPITS	AC	1.00	80.1	87.5	-7.4	81.9	-1.7
TANAN	AG	1.00	35.6	35.3	0.3	26.4	9.3
RESOL	CG	0.	7.5	4.7	2.7	6.5	1.0
MONTG	CG	1.00	-41.0	-44.0	2.9	-42.7	1.7
BERMU	AD	1.00	-46.4	-52.4	6.0	-39.8	-6.6
PIARC	CD	1.00	-51.3	-55.7	4.4	-56.1	4.8
MAKAP	AD	1.00	-54.2	-53.9	-0.3	-45.2	-9.0
ROME.	AD	1.00	-43.5	-49.1	5.6	-43.6	0.1
ROME.	DG	1.00	20.5	23.4	-2.9	23.4	-2.9
BERMU	DG	1.00	-13.9	-5.4	-8.6	-6.1	-7.9
LA-MO	AG	1.00	-10.6	-11.4	0.8	-4.0	-6.6
SARDI	AD	1.00	81.8	72.7	9.2	61.4	20.4
SARDI	DG	1.00	-17.4	-16.0	-1.4	-8.2	-9.1
NORFO	DG	1.00	12.8	15.4	-2.6	13.7	-0.9
RIO-D	DG	1.00	-61.5	-59.5	-2.0	-61.6	0.2
RIO-D	AG	0.	-97.9	-78.7	-19.2	-76.6	-21.3
FARNB	AD	1.00	73.5	65.6	8.0	56.1	17.5
NORFO	AD	1.00	-71.8	-64.9	-6.8	-51.1	-20.6
NORFO	AG	1.00	-54.0	-49.5	-4.4	-37.4	-16.5
TANAN	AD	1.00	88.4	80.4	8.0	70.0	18.4
BELEM	AD	1.00	-23.8	-27.4	3.7	-19.8	-4.0
BELEM	AG	1.00	-97.5	-83.8	-13.7	-80.6	-16.9
LA-MO	CG	1.00	-0.3	-6.7	6.4	-8.4	8.1
BELEM	AC	1.00	21.7	24.0	-2.3	33.4	-11.7
BELEM	CD	1.00	-45.0	-51.4	6.5	-53.2	8.2
LA-MO	AC	1.00	-7.3	-4.7	-2.6	4.4	-11.8
LA-MO	CH	1.00	51.1	58.3	-7.2	45.7	5.4
RIO-D	AD	1.00	-21.8	-19.2	-2.6	-15.0	-6.9
RIO-D	CG	1.00	-96.2	-93.7	-2.5	-96.1	-0.1
FARNB	DG	1.00	-7.9	0.3	-8.2	5.8	-13.7
HESTM	CD	1.00	-43.0	-52.2	9.1	-48.7	5.7
NEA.M	AG	1.00	65.2	68.2	-3.0	65.5	-0.3
NEA.M	GH	0.	16.0	8.7	7.3	1.2	14.8
SABAN	AC	1.00	10.0	6.5	3.5	16.7	-6.7
SABAN	CD	1.00	-57.3	-59.5	2.2	-59.3	2.0
NEA.M	AH	1.00	73.4	76.9	-3.5	66.7	6.7
PIARC	AC	1.00	17.6	12.7	4.9	20.8	-3.2
PIARC	AD	1.00	-37.9	-43.0	5.1	-35.3	-2.6
SABAN	AD	1.00	-50.6	-53.0	2.4	-42.6	-8.1
SABAN	DG	1.00	-41.5	-39.8	-1.7	-39.3	-2.2
TSUSH	CD	1.00	47.2	43.0	4.2	34.5	12.7
HESTM	DG	0.	40.8	28.6	12.2	32.2	8.6
SABAN	AG	0.	-96.8	-92.8	-4.0	-81.8	-15.0
SABAN	CG	0.	-98.7	-99.3	0.6	-98.6	-0.1
VILAN	AD	0.	25.1	25.0	0.1	22.8	2.3
VILAN	AG	1.00	-3.4	3.8	-7.2	7.0	-10.4
VILAN	DG	0.	-22.6	-21.3	-1.4	-15.8	-6.8
			RMS ESTIMATION ERRORS =		5.188	=	8.864

TABLE 1

TABLE OF RESIDUAL ERRORS (DAY)

NIGHT STATISTICS

SITE	LOP	WEIGHT	OBSERVED	NEW COEFFICIENTS PREDICTED	NEW COEFFICIENTS ERROR	OLD COEFFICIENTS PREDICTED	OLD COEFFICIENTS ERROR
NELC.	CG	1.00	-4.9	-5.5	0.6	-5.7	0.8
ROME.	CG	1.00	-5.8	-2.5	-3.3	-0.6	-5.2
MIAMI	CG	1.00	1.4	-2.4	3.8	-1.7	3.0
BERMU	AG	1.00	-16.6	-19.0	2.4	-10.6	-6.0
ROME.	AG	1.00	-22.0	-24.4	2.5	-19.9	-2.0
MIAMI	AG	1.00	-25.9	-35.5	9.6	-23.7	-2.2
BERMU	AC	1.00	-15.0	-14.7	-0.2	-11.7	-3.2
ROME.	AC	1.00	-13.8	-21.9	8.1	-19.3	5.5
BERMU	CG	1.00	-1.0	-4.3	3.3	1.1	-2.1
CORAL	AC	1.00	-6.1	-1.4	-4.7	-5.0	-1.1
FARNB	AG	1.00	-3.4	2.6	-6.0	-0.1	-3.3
GRAND	CG	1.00	13.7	15.1	-1.3	8.6	5.1
SARDI	AG	1.00	-4.4	-6.9	2.5	-2.8	-1.6
TANAN	AG	1.00	-3.8	-3.2	-0.7	-4.3	0.5
RESOL	CG	1.00	-6.2	4.3	-10.4	3.9	-10.1
RESOL	AC	0.	4.8	5.0	-0.2	-1.3	6.1
MONTG	CG	1.00	-4.0	-2.3	-1.6	-2.0	-2.0
RESOL	AG	0.	-1.6	9.3	-10.9	2.6	-4.3
PIARC	CD	1.00	9.8	7.5	2.3	2.1	7.8
MAKAP	AD	1.00	-29.1	-34.7	5.6	-23.2	-5.9
LA-MO	AG	1.00	-31.3	-25.0	-6.3	-20.6	-10.7
SARDI	AD	1.00	35.5	29.3	6.3	20.5	15.0
SARDI	DG	1.00	-38.3	-36.2	-2.1	-23.2	-15.0
RIO-D	DG	1.00	1.2	-0.2	1.4	7.6	-6.4
FARNB	AD	1.00	31.7	30.9	0.8	21.2	10.5
NORFO	AG	1.00	-31.7	-27.8	-3.9	-21.3	-10.4
BELEM	AD	1.00	11.7	6.2	5.5	6.7	5.0
LA-MO	CG	1.00	-0.8	4.2	-5.1	1.9	-2.7
BELEM	AC	1.00	-8.0	-6.6	-1.3	3.5	-11.5
BELEM	CD	1.00	9.6	12.9	-3.3	3.2	6.4
LA-MO	AC	0.	-27.6	-29.3	1.7	-22.5	-5.1
TANAN	AD	0.	35.1	21.0	14.2	7.8	27.3
RIO-D	CG	1.00	6.2	7.8	-1.7	5.9	0.3
SABAN	CD	1.00	8.1	3.4	4.8	1.5	6.7
NEA.M	AG	1.00	-8.2	-6.1	-2.1	-2.2	-6.0
LA-MO	CH	1.00	42.1	33.2	8.9	24.6	17.5
NEA.M	AD	1.00	28.7	32.7	-4.0	21.6	7.1
NEA.M	AH	1.00	4.9	6.6	-1.7	-0.1	5.0
SABAN	AD	1.00	0.1	-14.0	14.1	-6.8	6.9
VILAN	AD	1.00	16.0	9.6	6.5	6.9	9.2
VILAN	AG	1.00	-5.9	-5.4	-0.5	-2.5	-3.4
VILAN	DG	0.	-14.7	-15.0	0.3	-9.4	-5.3
HESTM	DG	0.	-38.5	-21.2	-17.3	-18.0	-20.5
MAKAP	DH	0.	-2.4	-10.2	7.9	-0.7	-1.7
NEA.M	GH	0.	-3.6	12.7	-16.3	2.1	17.1
OROTE	DH	1.00	-16.4	-6.3	-10.1	2.8	-19.2
SABAN	AC	0.	-16.2	-17.4	1.2	-8.3	-7.9
VILAN	AH	1.00	39.3	30.5	8.8	14.4	24.9
				RMS ESTIMATION ERROR =	5.400	=	8.761

TABLE 2

TABLE OF RESIDUAL ERRORS (NIGHT)

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Table 3—Special Cases (new coefficients vs old coefficients)

site	LOP	predicted day residual error* new	predicted day residual error* old	predicted night residual error* new	predicted night residual error* old
BERMU	AC	6.9	−3.6	0.9	−3.2
HESTM	CD	9.1	5.7	no night data	
MIAMI	AG**	no day data		9.8	−2.2
SPITS	AC	−7.4	−1.7	no night data	
ROME	AC	3.6	1.0	8.7	5.5
SABAN	AD	2.4	−8.1	14.1	6.9

* units of centicycles

**may be subject to modal interference at night

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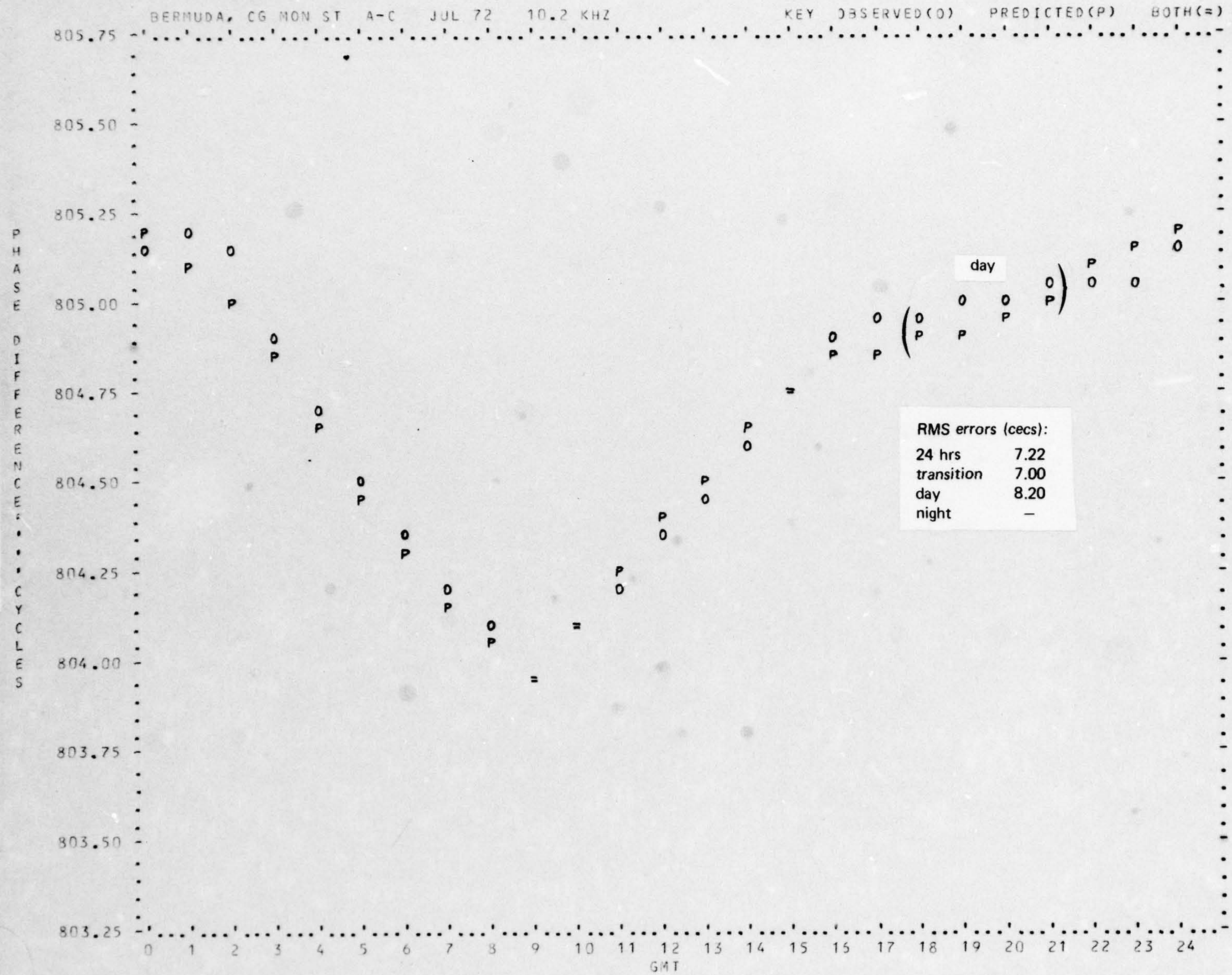

Figure 1. BERMU AC, new coefficients

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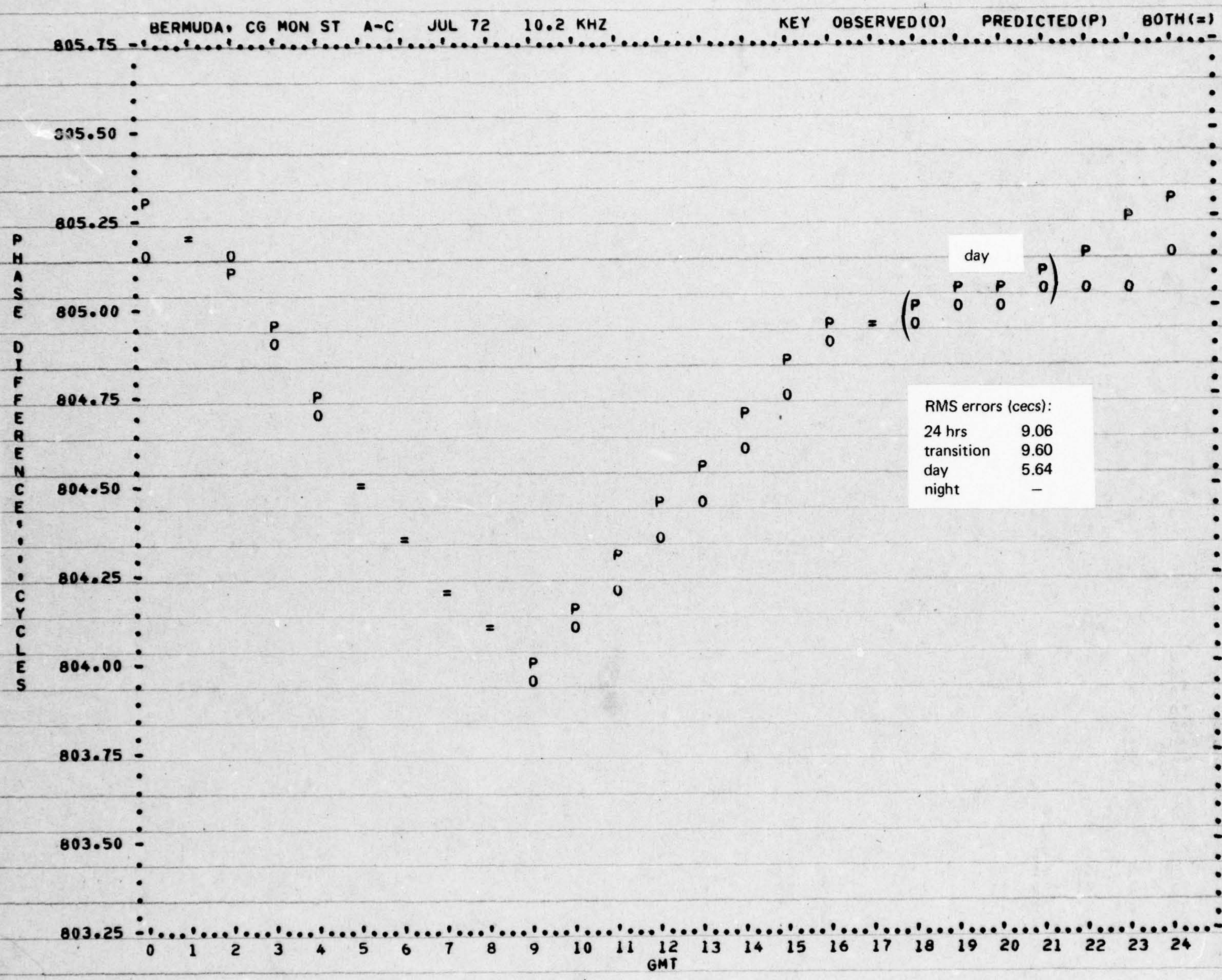

Figure 2. BERMU AC, old coefficients

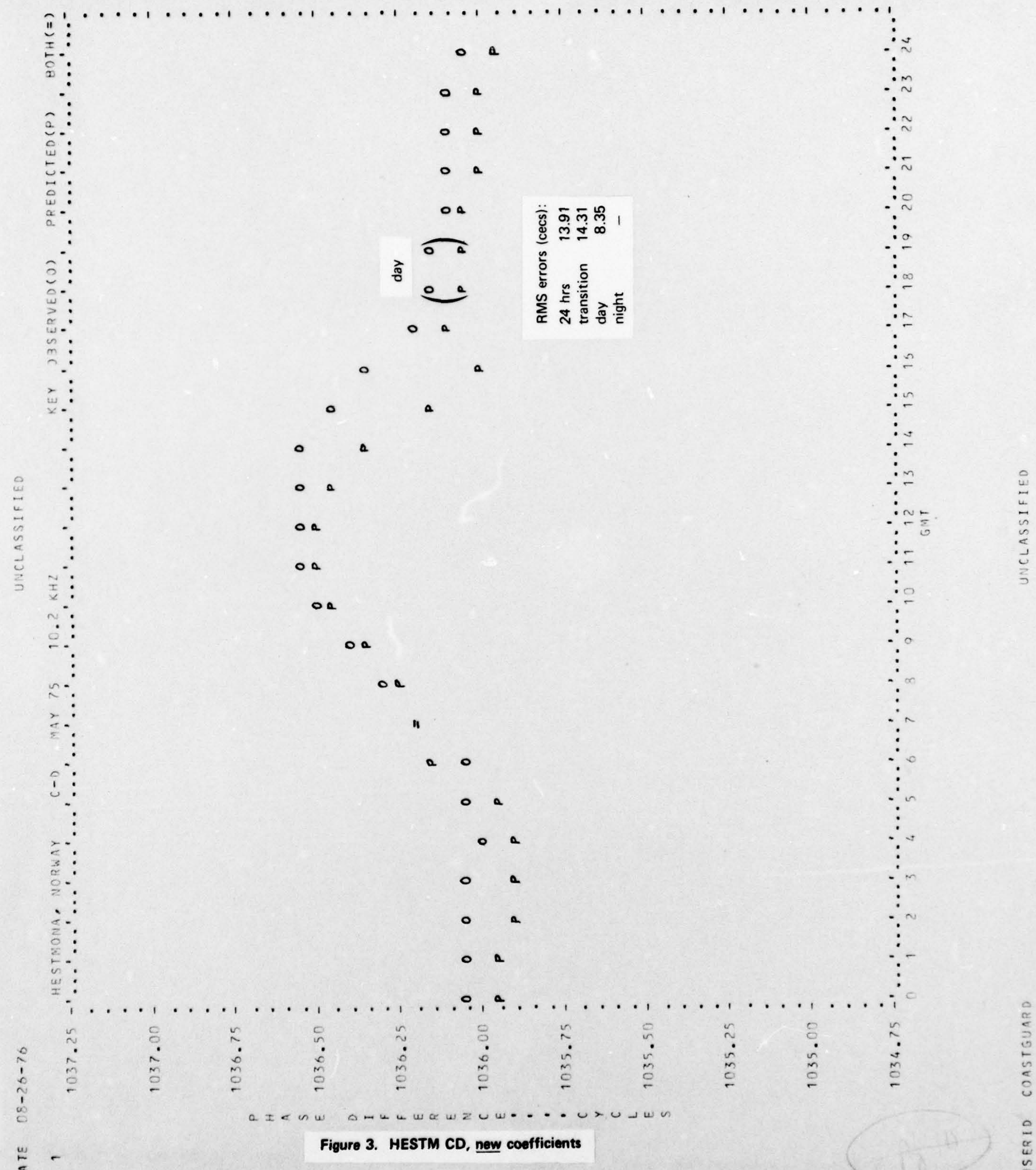

Figure 3. HESTM CD, new coefficients

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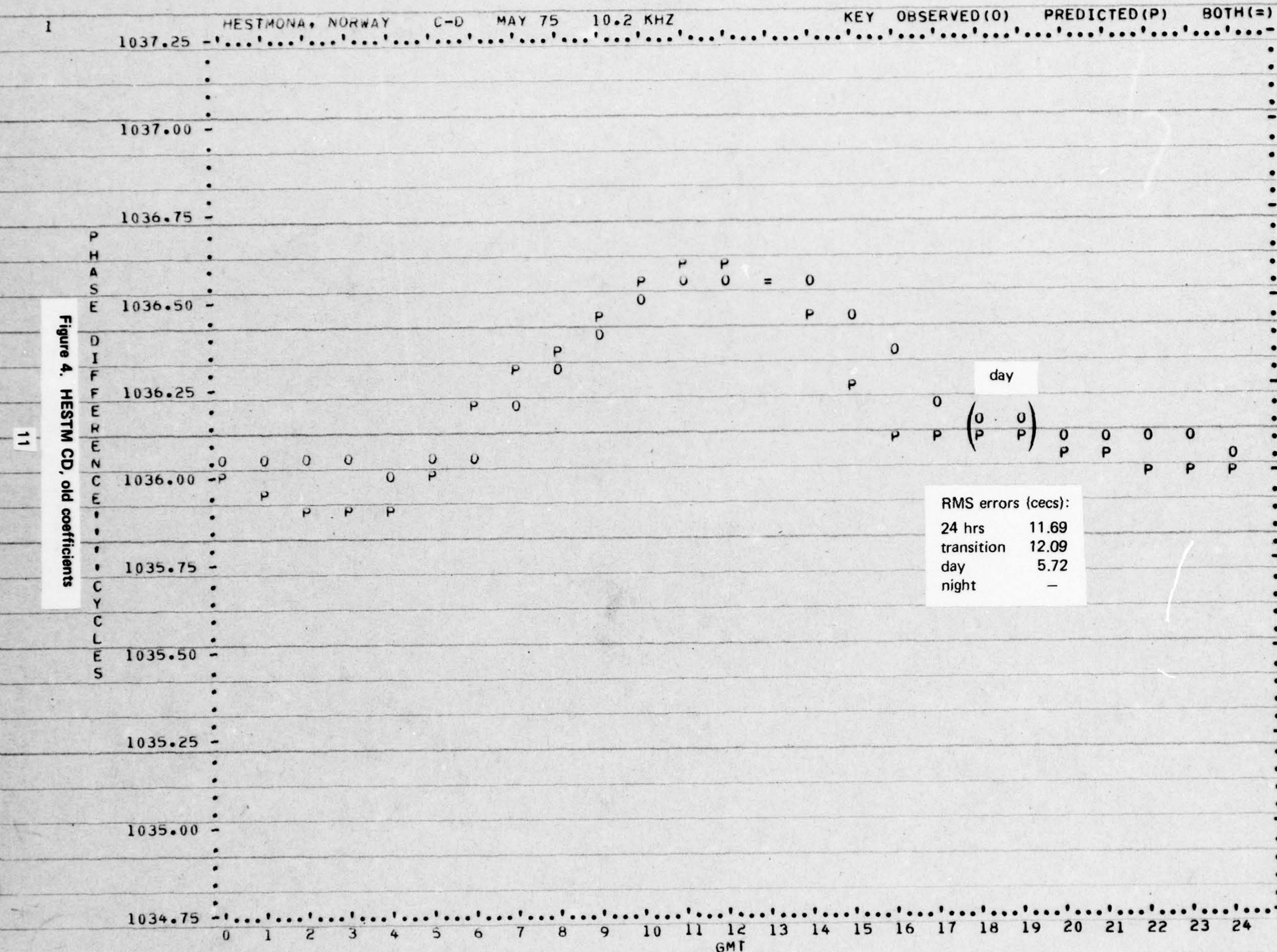

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Figure 4. HESTM CD, old coefficients

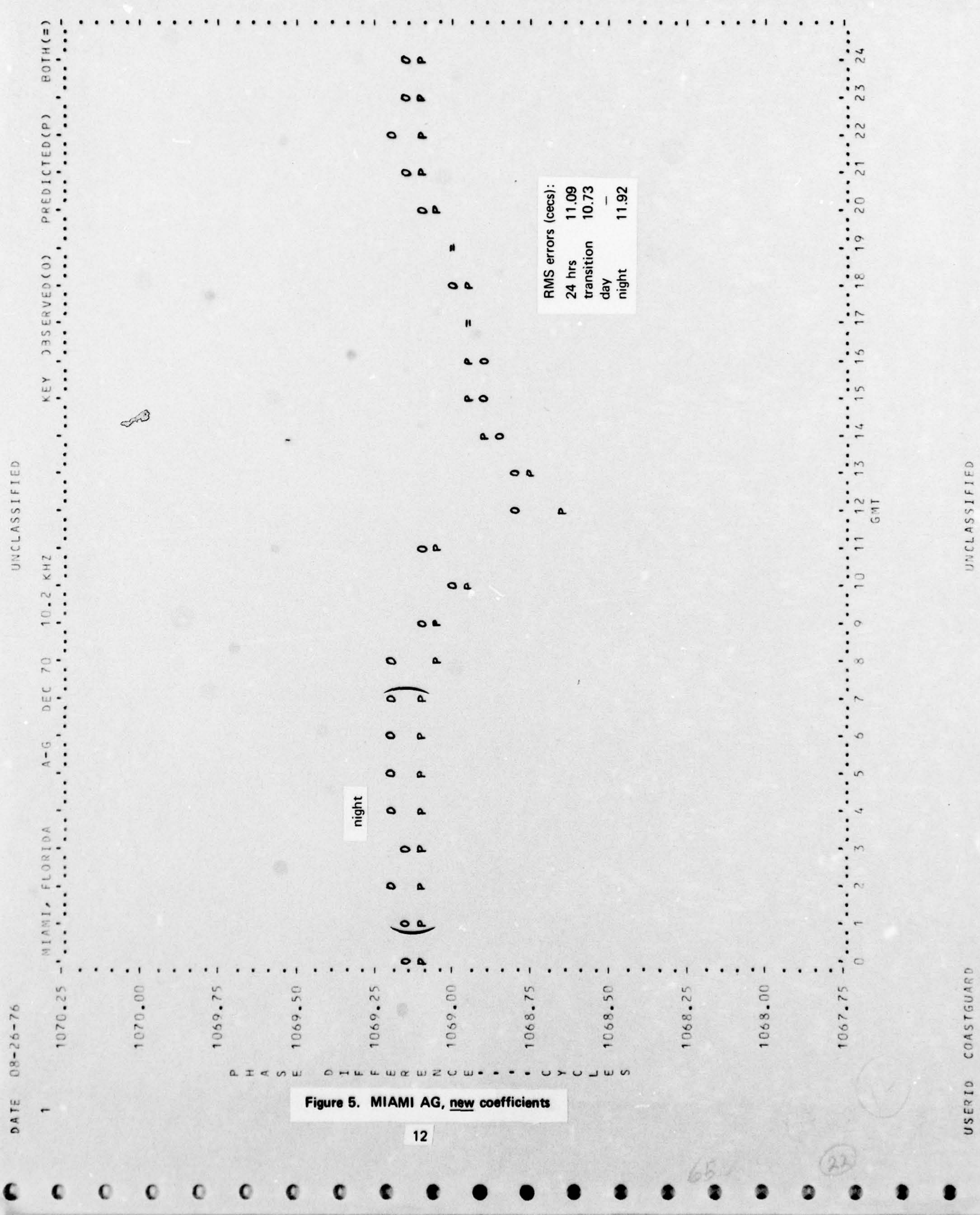

Figure 5. MIAMI AG, new coefficients

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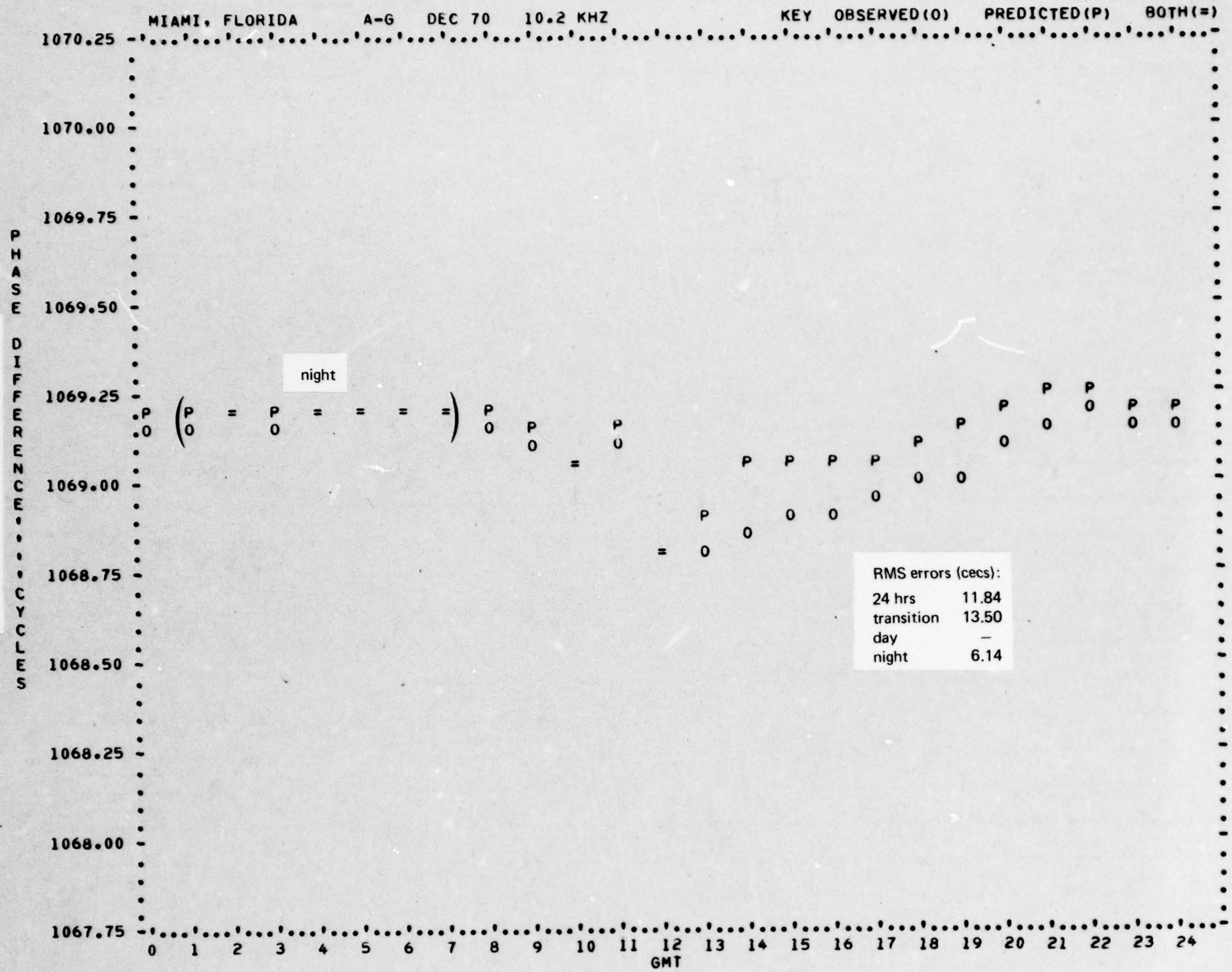

Figure 6. MIAMI AG, old coefficients

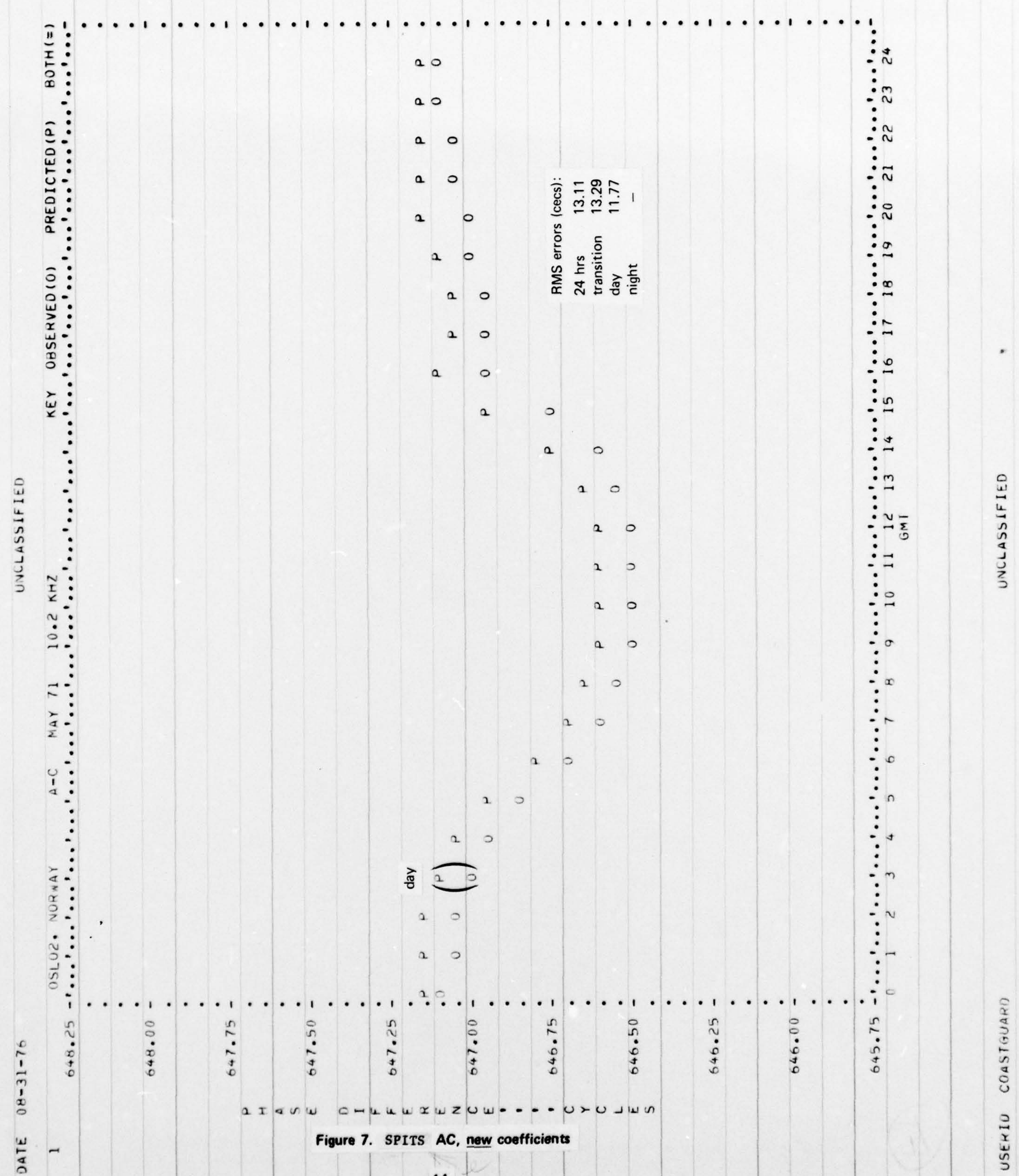

Figure 7. SPITS AC, new coefficients

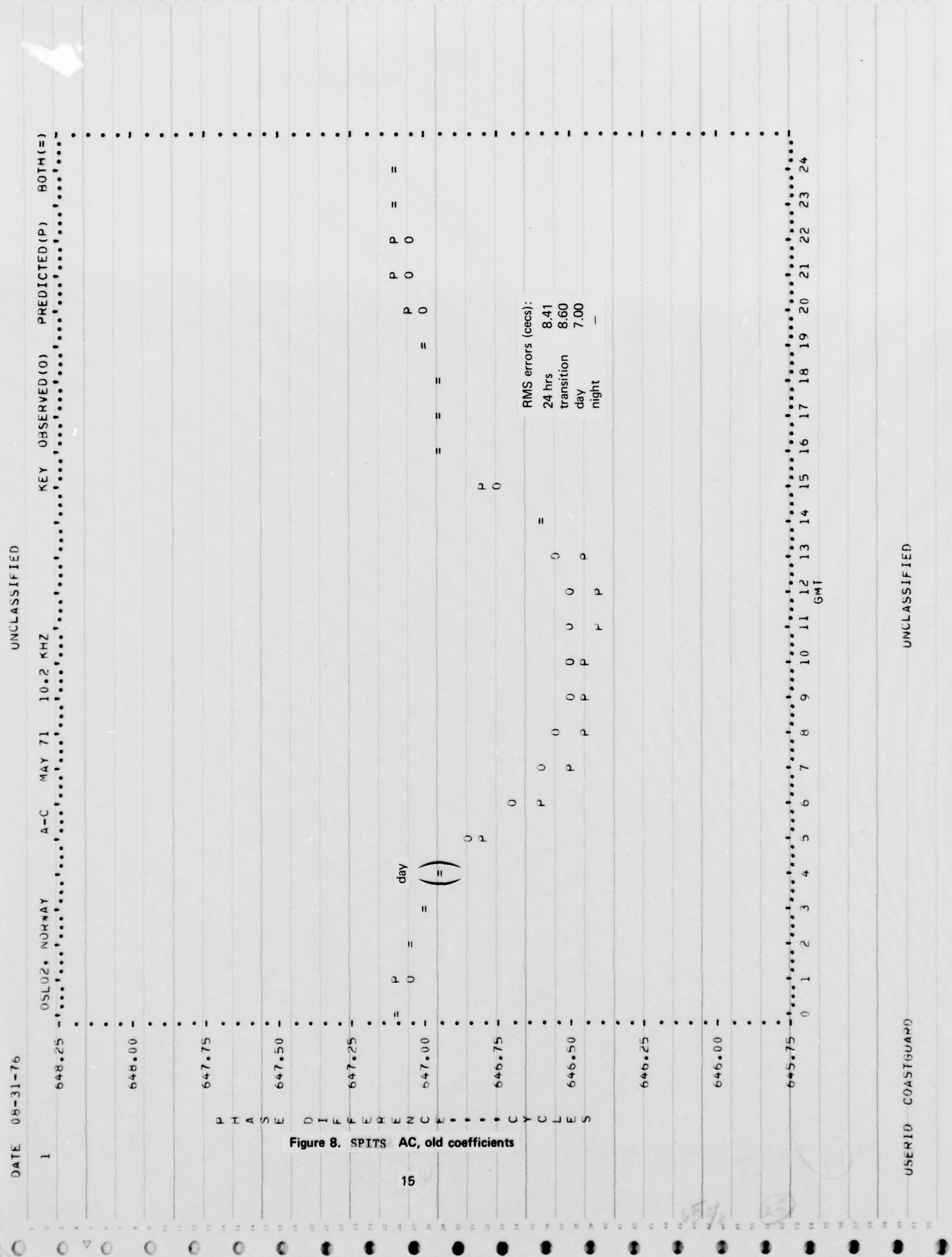

Figure 8. SPITS AC, old coefficients

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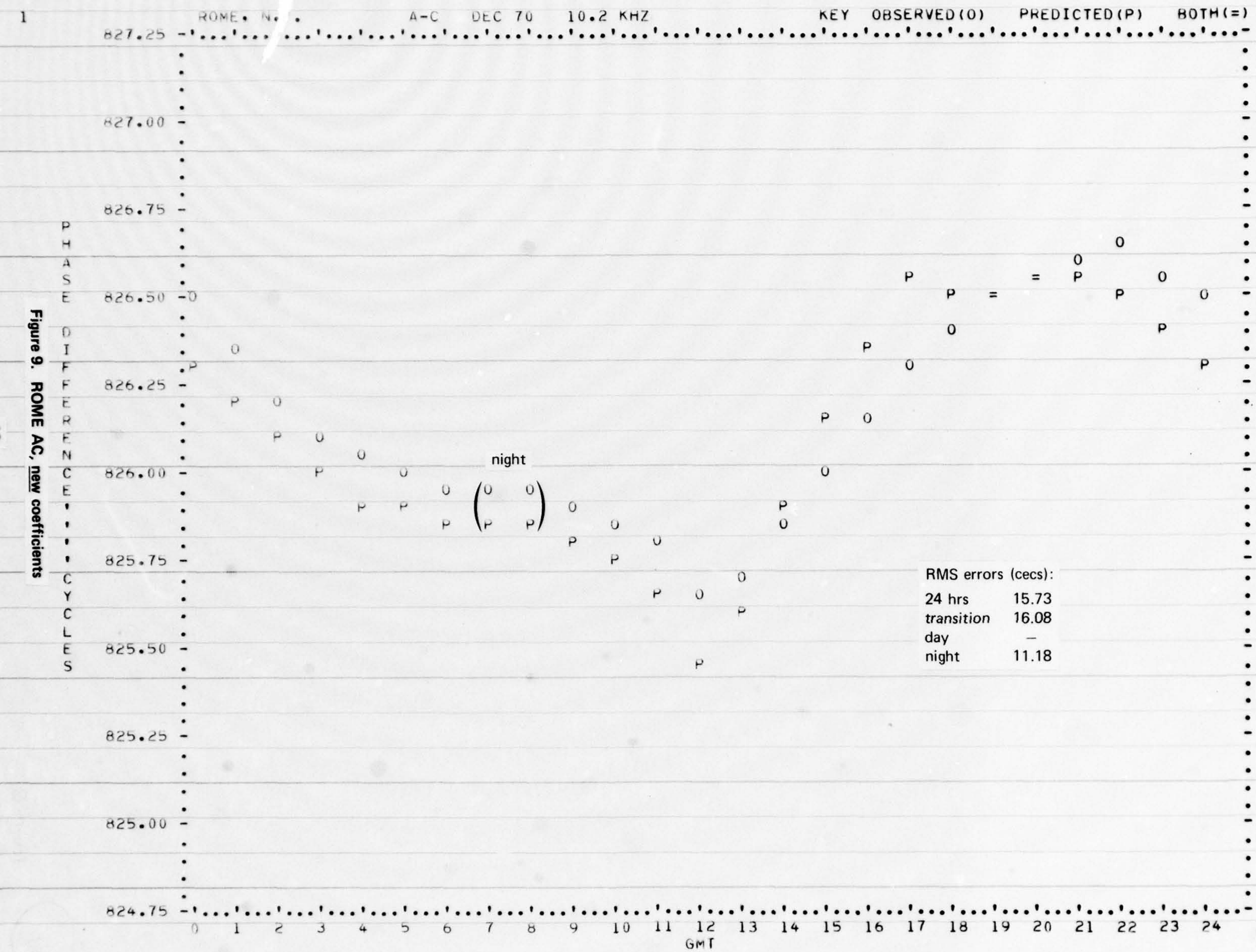

Figure 9. ROME AC, new coefficients

USERID COASTGUARD UNCLASSIFIED

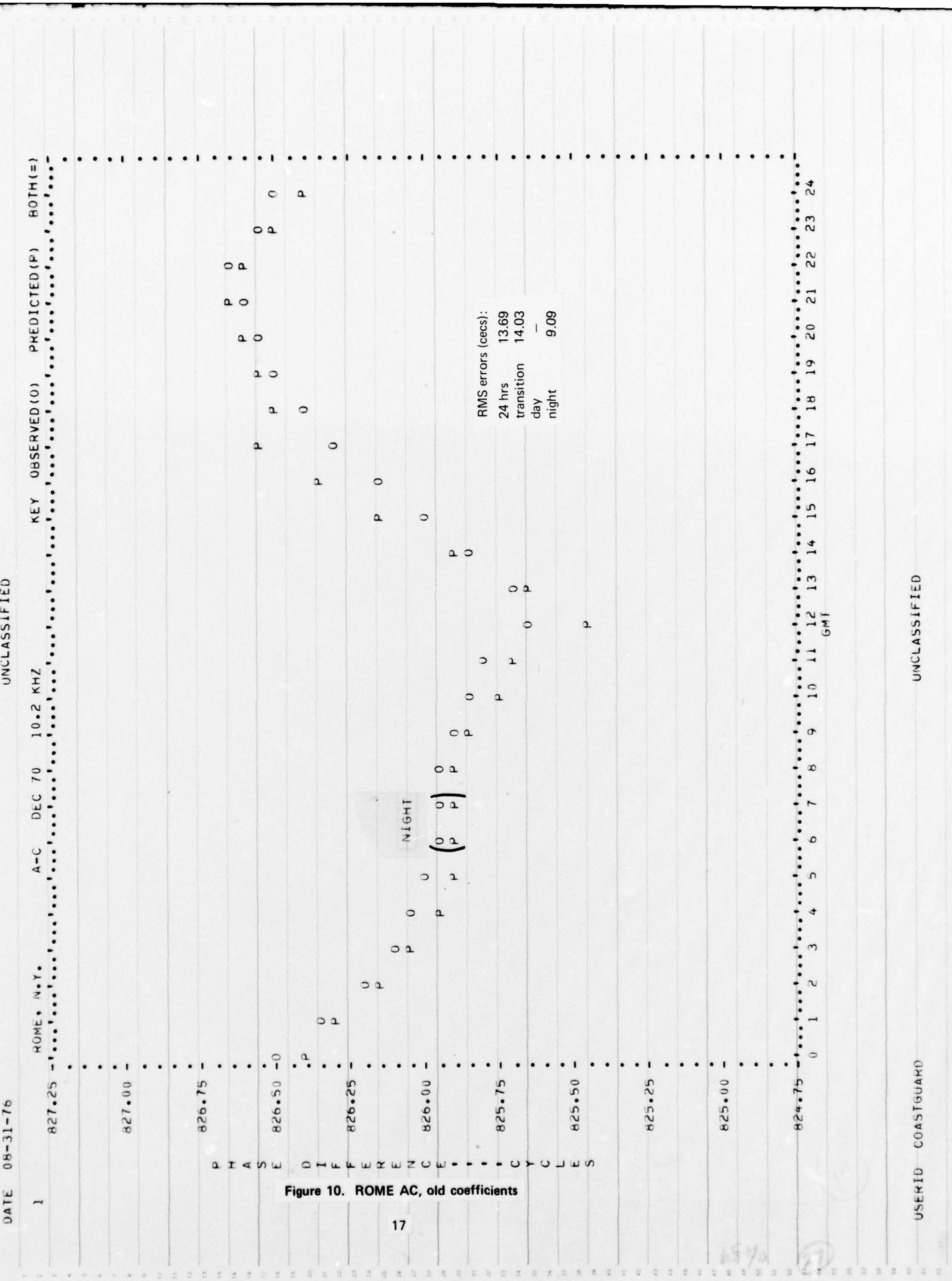

Figure 10. ROME AC, old coefficients

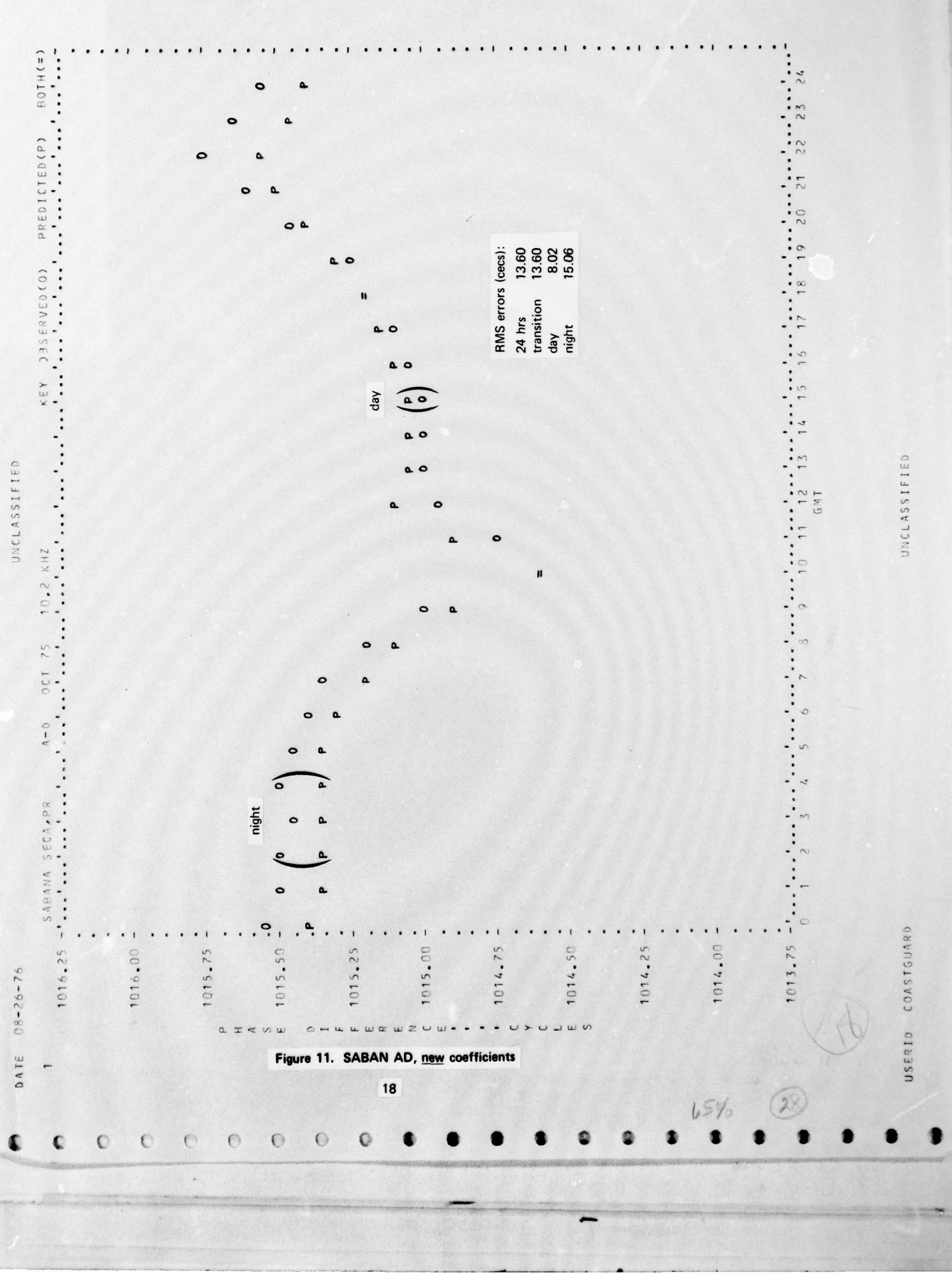

Figure 11. SABAN AD, new coefficients

65%

28

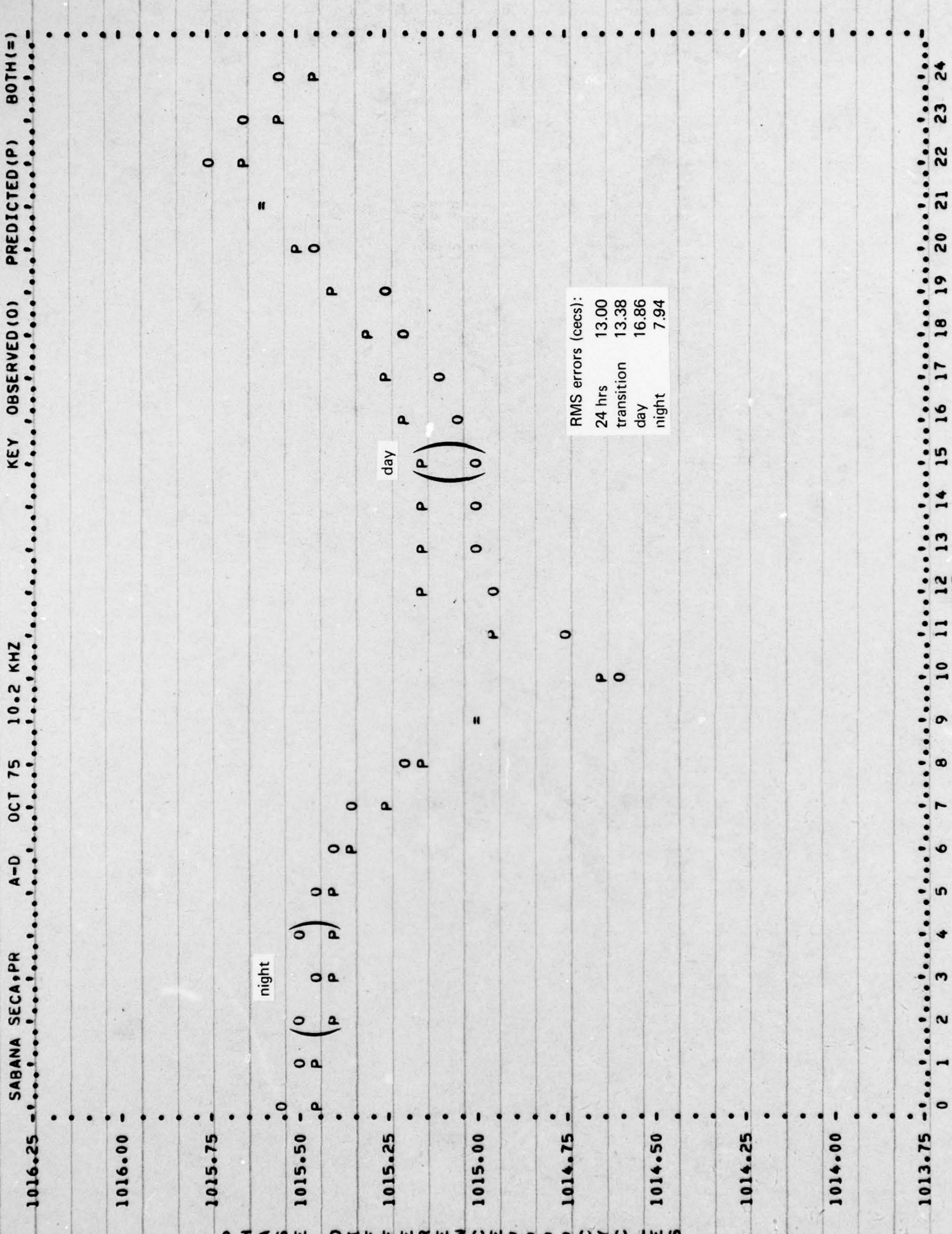

Figure 12. SABAN AD, old coefficients

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UNCLASSIFIED

1

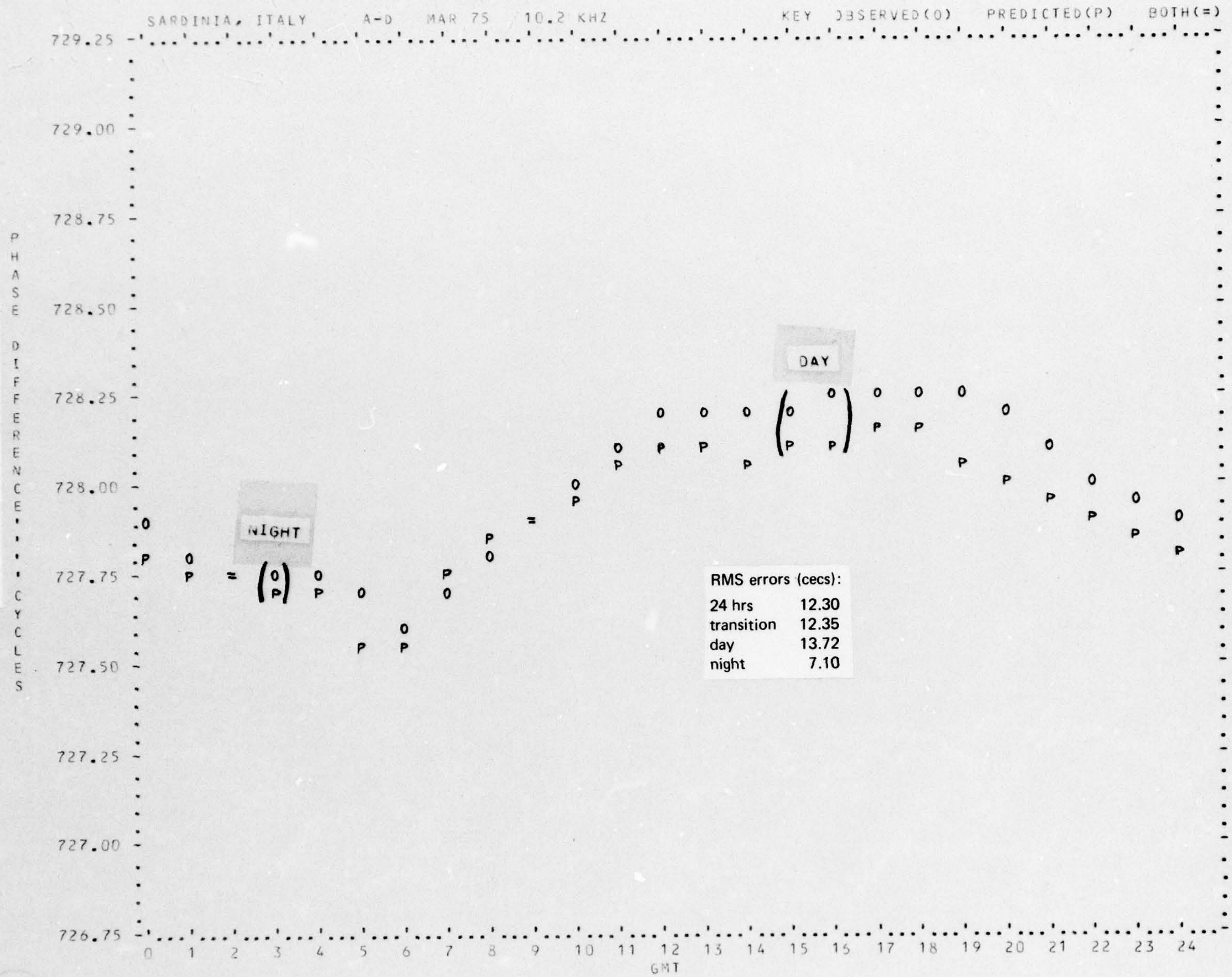

Figure 13. SARDI AD, new coefficients

65%

(30)

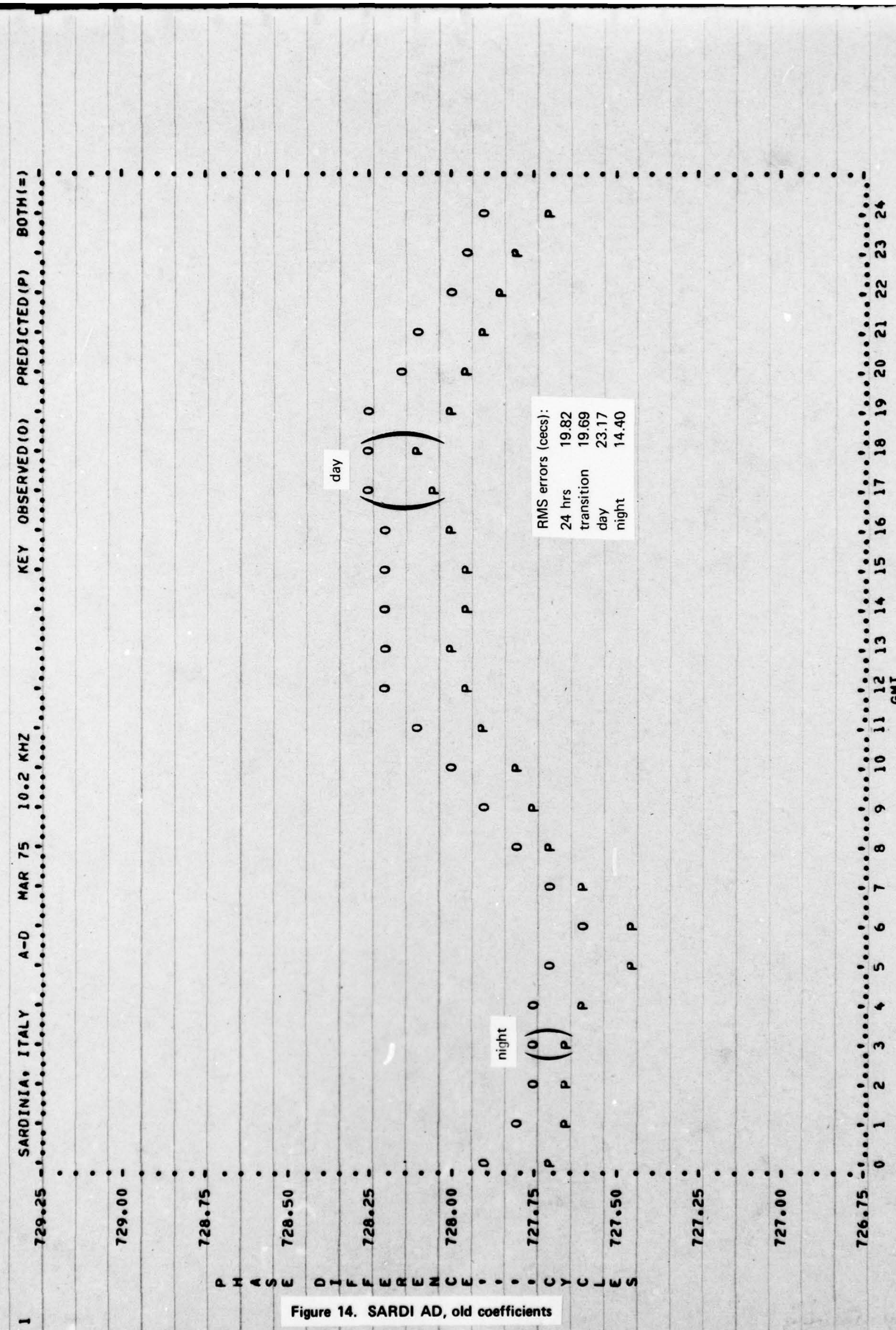

Figure 14. SARDI AD, old coefficients

DATE 08-26-76 UNCLASSIFIED

1

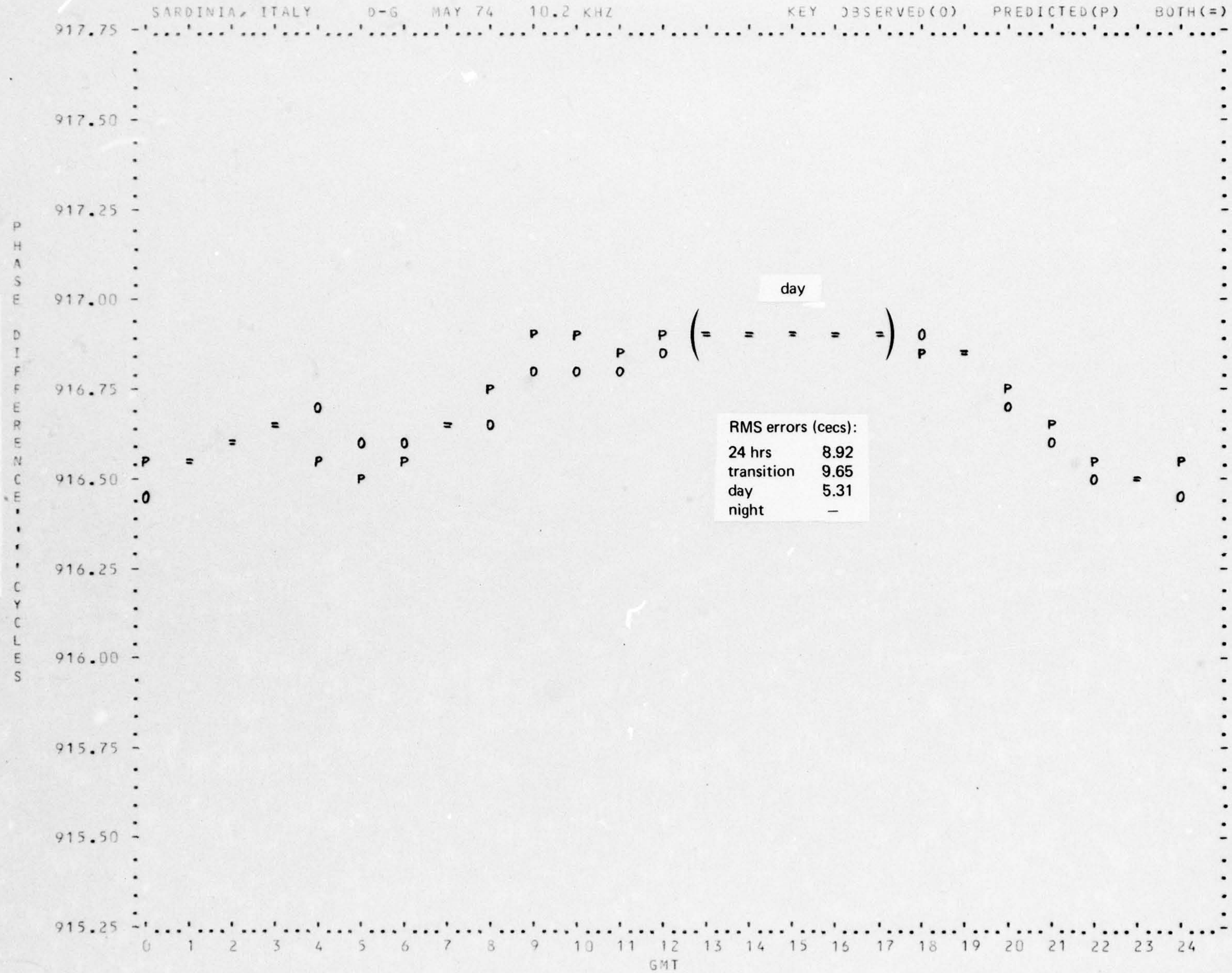

Figure 15. SARDI DG, new coefficients

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USERID COASTGUARD UNCLASSIFIED

DATE 07-26-76 UNCLASSIFIED

1

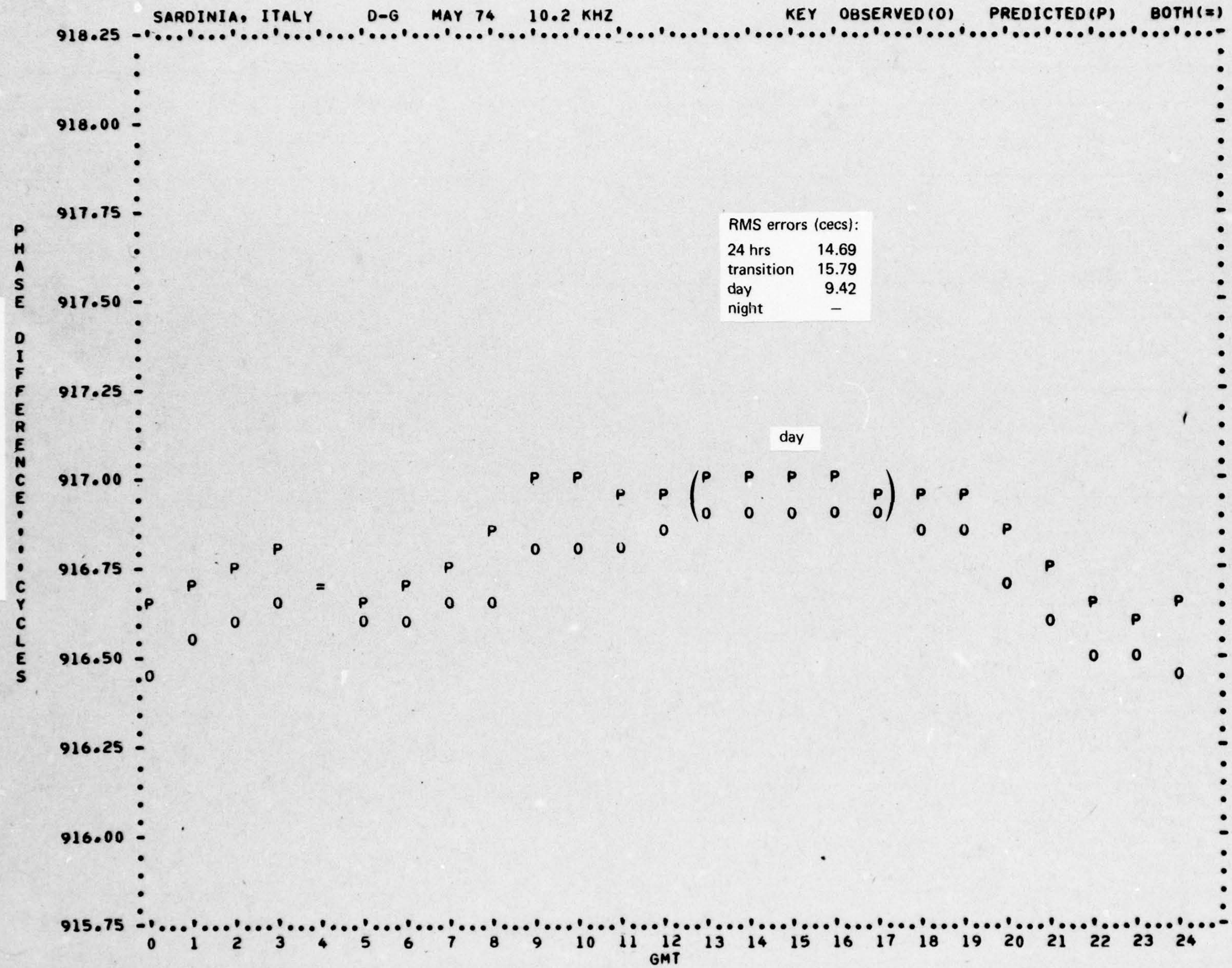

Figure 16. SARDI DG, old coefficients

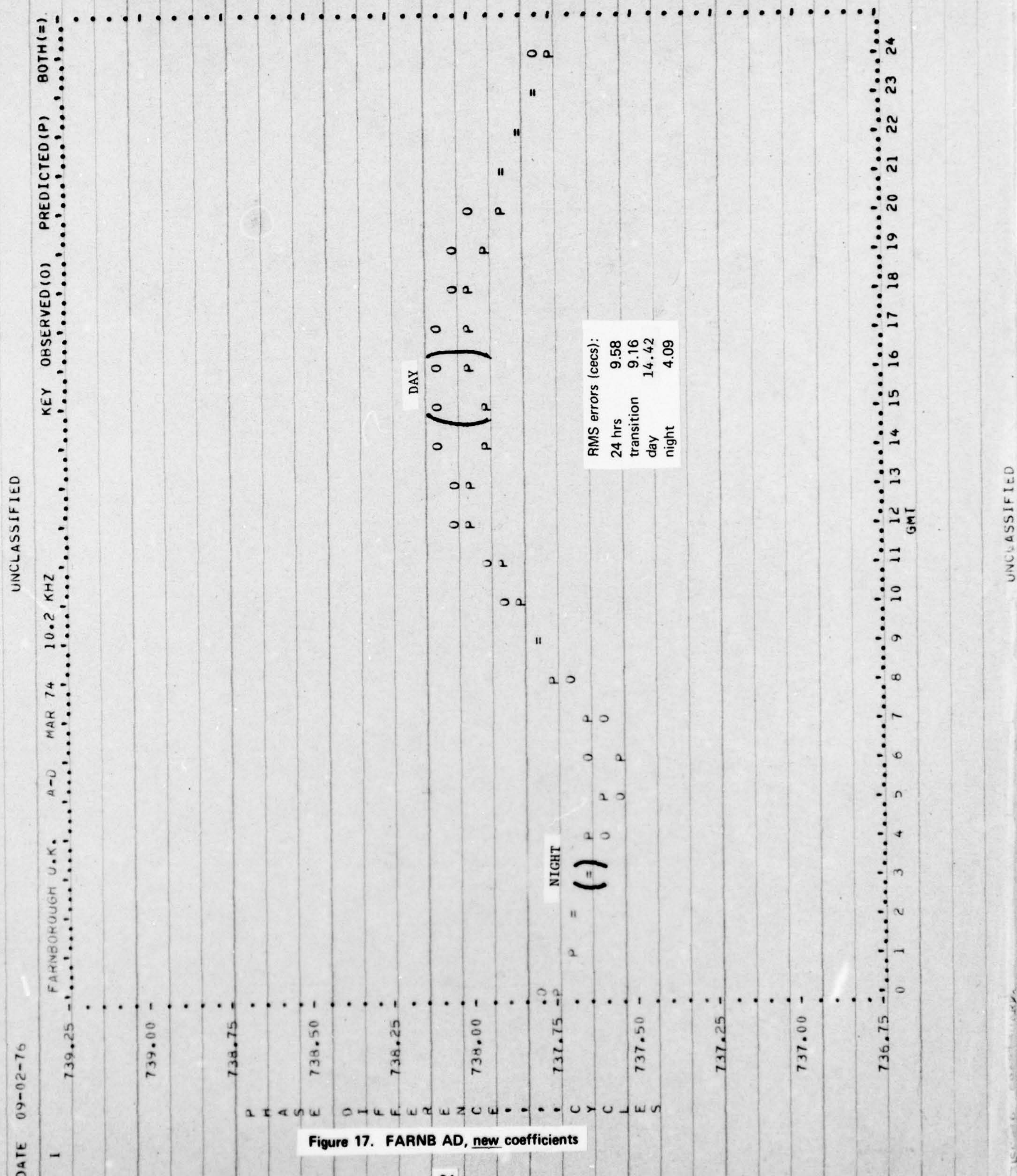

Figure 17. FARNB AD, new coefficients

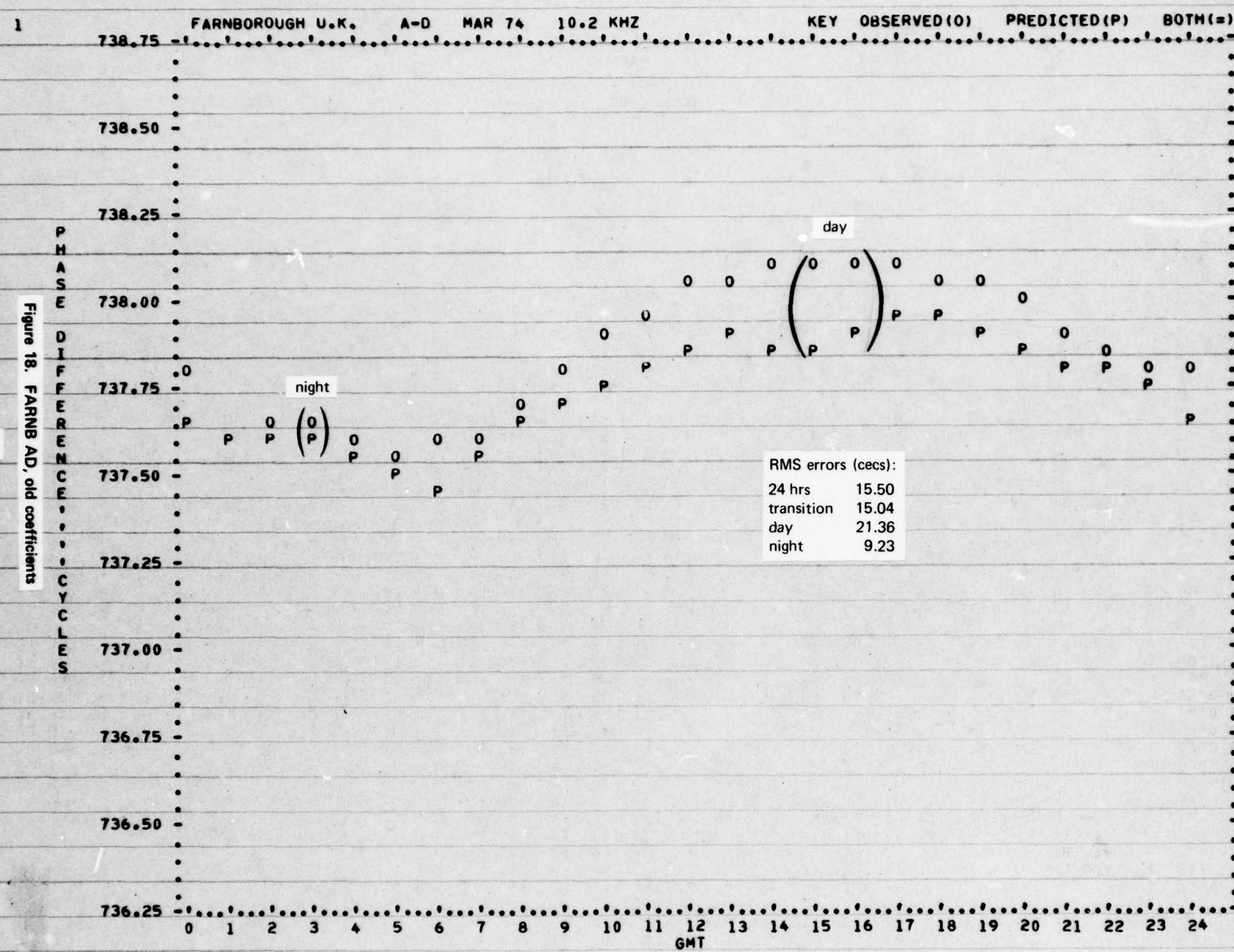

Figure 18. FARNB AD, old coefficients

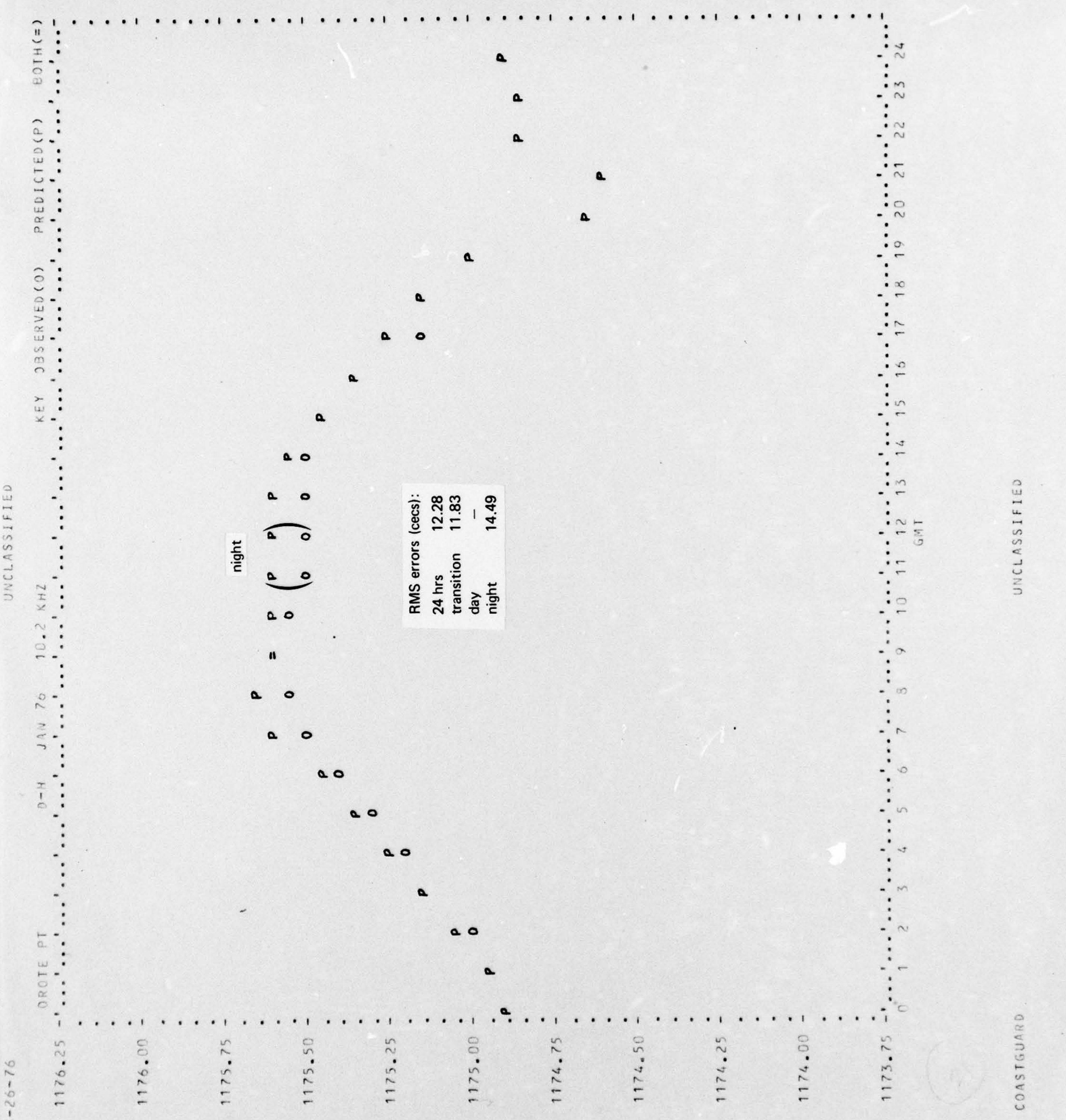

Figure 19. OROTE DH, new coefficients

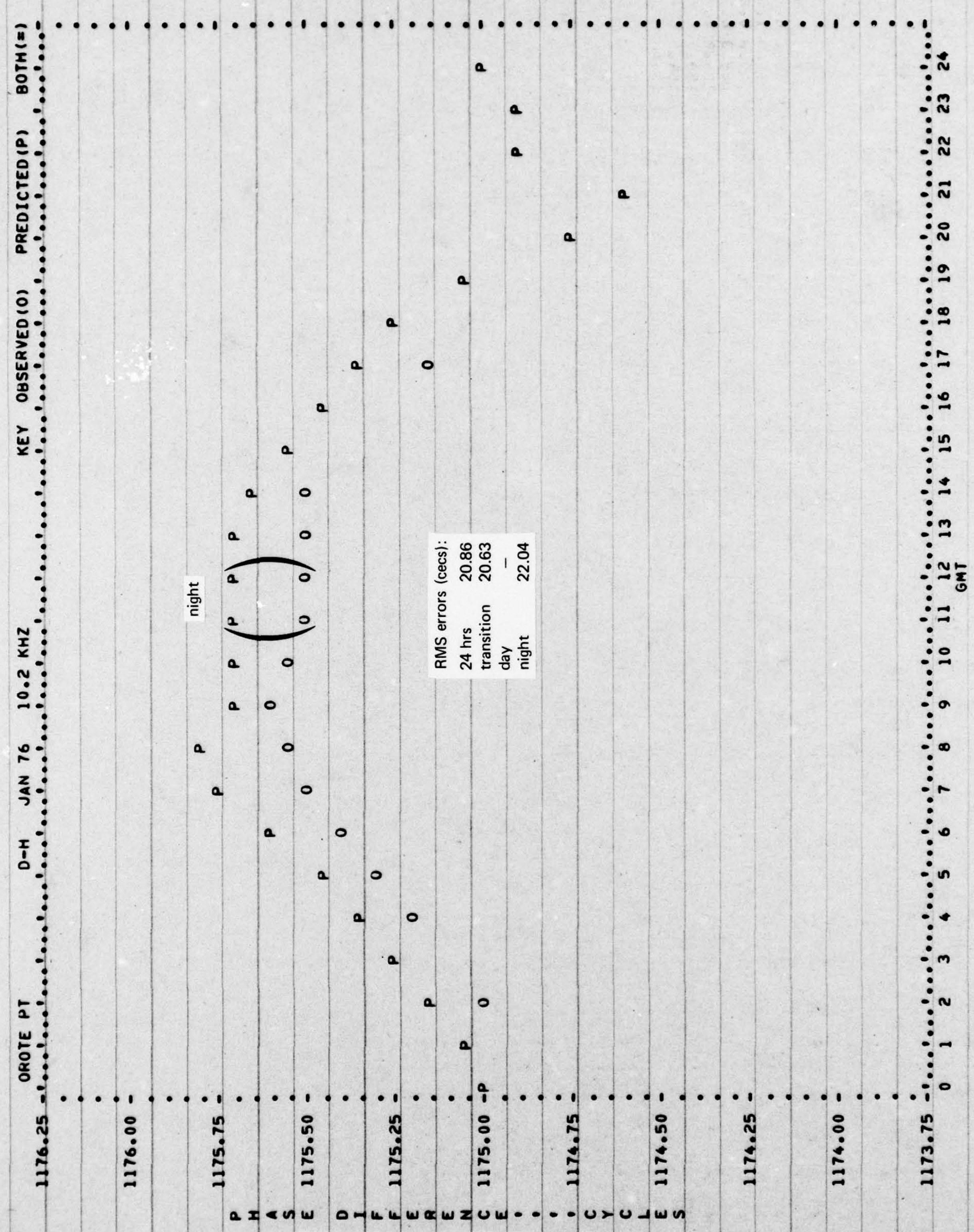

Figure 20. OROTE DH, old coefficients

F and their reciprocals, some severe errors are encountered for the new coefficients (on the order of 40 cecs)! The data on these paths is quite sparce but considered reliable. Thus, indications are that a serious model deficiency exists for paths crossing the geomagnetic equator. Moreover, the problem is further complicated by the observation that two such inter-hemispheric paths when phase differenced, e.g., A-D at TANAN, do *not* manifest this difficulty. The present data base is totally inadequate to resolve the problem. Obviously the next step in improving prediction accuracy will be first towards expanding the data base to include more southern and interhemispheric single station data and next towards examining further the validity and sophistication of the submodels themselves (particularly the geomagnetic submodels)!

IV. Recommendations

At present the only area of the world which suffers from consistent, serious prediction errors is the Mediterranean Sea (represented by FARNB, SARDI and NEA,M data). The Mediterranean errors are well documented in an NELC working paper (see reference 7) and are known to result from inaccuracies (on the order of 10 to 20 cecs) in predicting the signal phase of station D. The new coefficients offer an improvement in predictions in the Mediterranean for all phase differences involving station D with a northern hemispheric transmitter. Thus, it is recommended that the new coefficients be applied in the Mediterranean for all northern hemispheric transmitters. However, these corrections should only be used in a phase difference mode!

The current data base, as demonstrated earlier, is not sufficiently comprehensive in its representation of inter-hemispheric paths nor does it have any information concerning the B, E and F transmitters. In addition, the current software needs modification to realistically process single station phase data. These deficiencies are serious. As such, the generation of any new PPC tables for public use should be restricted to only those areas, i.e., the Mediterranean, which show serious problems now and which we confidently believe can be alleviated by the new coefficients.

References

1. Swanson, E.R. and Brown, R.P., "Omega Propagation Prediction Primer", NELC TN2102, 1972.
2. Morris, P.B. and Cha, M.Y., "Omega Propagation Corrections: Background and Computational Algorithm", ONSOD-01-74.
3. "Omega Predicted Propagation Corrections Program Documentation", The Analytic Sciences Corp., TR-211-10, 1973.
4. Bradford, W.R., "Effects of Magnetic Dip Angle and Azimuth on Phase Velocity at 10.2 kHz", NELC TN A107, 1974. (Working Paper)
5. "Phase Coefficient Determination Program Documentation", The Analytic Sciences Corp., TR-343-3, 1973.
6. "Evaluation of Coverage and Anomalous Propagation Effects for Alternative G Transmitter Sites", The Analytic Sciences Corp., TR-343-14, 1975.
7. Swanson, E.R., "Omega Prediction Errors in the Mediterranean", NELC TN 3191, 1976.

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APPENDIX A

New Coefficients
(* 10^4)

no.	k_D	confidence interval* (for new coefs)	k_D (old)	k_N	confidence interval* (for new coefs)	k_N (old)
1	39.41	± 3.4	35.2	9.62	± 4.9	4.4
2	12.91	± 7.5	6.0	11.66	±12.1	9.4
3	0.	–	0.	7.59	±10.5	7.2
4	–8.59	± 9.9	–12.0	18.09	±17.2	14.0
5	–37.66	±23.0	–6.6	–58.4	±42.2	–45.0
6	–29.27	±31.8	0.	–77.78	±47.5	–17.6
7	29.19	±42.0	0.	140.81	±72.9	45.0
8	–16.67	±12.2	1.0	19.16	±26.8	0.0
9	0.	–	0.	–6.36	± 6.4	–4.0
10	0.	–	0.	7.02	±17.6	15.0
11	11.9 **	–	11.9	15.9**	–	15.9
12	56.32	±37.4	10.0	4.48	±49.8	5.0
13	1.53	± 1.8	1.0	0.76	± 2.3	0.9

* determined by student t-distribution.

**this coefficient can only be determined by near-field data which could not be processed here. The previous value was retained. Subsequent data analysis has shown this value to be quite accurate.

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APPENDIX B

Monitor Sites

CODE	SITE	LAT	LONG
1	NELC, **	32.70800	−117.24650
3	BERMU**	32.26470	−64.87680
9	FARNB**	51.28800	−0.75420
11	SARDI **	39.18100	9.15970
13	ROME, **	43.22400	−75.41020
15	WALES**	65.61220	−168.09170
16	MIAMI **	25.78950	−80.30050
17	CORAL**	64.18670	−83.34220
18	GRAND**	55.17000	−118.84300
19	OSLO, **	59.93830	11.08360
20	SPITS **	78.92330	11.94920
21	RESOL **	74.71388	−94.97333
22	HESTM **	66.52930	12.84530
23	TANAN**	−18.91833	47.55056
24	PIARC **	10.59550	−61.34970
25	MAKAP**	21.30780	−157.65060
26	MONTG**	32.35592	−86.30772
27	LA-MO **	46.55950	−98.63880
28	NORFO**	36.92555	−76.29222
29	RIO-D **	−22.87069	−43.13222
30	TELEC **	39.99567	−105.26225
31	BELEM **	−1.39159	−48.44496
32	NEA,M **	38.10028	23.97833
33	SABAN **	18.45750	−66.21472
34	TSUSH **	34.32470	129.20640
35	OROTE **	13.66890	144.61720
36	VILAN **	38.76138	−27.13116

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INPUT DATA SUMMARY

FREQUENCY = 10.2 KHZ
7005 THROUGH 7603

DAY PHASE DATA
NUMBER OF MEASUREMENTS = 61
INDEPENDENT MEASUREMENTS = 45

NIGHT PHASE DATA
NUMBER OF MEASUREMENTS = 61
INDEPENDENT MEASUREMENTS = 47

CODE	SITE	XMTR PAIR	APPROX NOMINAL LOP (CYCLES)	DAY MONTHS OF DATA	DAY AVERAGE PHASE VARIATION DPHI (CENTICYCLES)	DAY MONTHLY STD DEV (CENTICYCLES)	NIGHT MONTHS OF DATA	NIGHT AVERAGE PHASE VARIATION DPHI (CENTICYCLES)	NIGHT MONTHLY STD DEV (CENTICYCLES)
3	BERMU	AC	805.	15	-6.7	5.0	3	-52.1	3.6
3	BERMU	AG	1030.	39	-20.9	7.1	29	19.2	5.0
1	NELC.	CG	833.	28	4.3	1.3	28	-27.6	4.1
13	ROME.	AC	826.	12	18.6	2.7	2	-31.1	2.6
13	ROME.	AG	961.	25	9.4	5.9	17	7.8	4.1
13	ROME.	CG	1035.	26	-7.5	2.7	24	41.3	4.6
11	SARDI	AG	745.	30	22.8	5.3	24	-41.9	4.6
15	WALES	AC	913.	3	-2.1	0.6	0	0.	0.
16	MIAMI	CG	1078.	11	-10.7	6.3	11	52.6	5.9
16	MIAMI	AG	1069.	0	0.	0.	3	26.7	4.5
3	BERMU	CG	1125.	17	-8.5	2.9	17	72.6	4.0
17	CORAL	AC	796.	1	20.5	0.	4	-30.8	1.8
9	FARNB	AG	723.	30	20.6	4.5	24	-48.2	2.5
18	GRAND	CG	831.	5	14.6	1.2	5	-15.3	1.0
20	SPITS	AG	659.	5	-5.6	1.5	2	-72.5	1.7
20	SPITS	AC	647.	5	9.5	4.1	0	0.	0.
23	TANAN	AG	815.	30	17.1	8.7	21	-18.4	9.5
21	RESOL	CG	884.	1	-11.3	0.	3	-22.3	4.4
21	RESOL	AC	784.	0	0.	0.	1	-19.1	0.
26	MONTG	CG	1022.	4	-5.9	2.8	5	34.9	2.2
21	RESOL	AG	768.	0	0.	0.	1	-41.7	0.
3	BERMU	AD	1001.	15	-21.4	5.7	12	10.6	7.6
24	PIARC	CD	1069.	8	-8.7	3.5	8	51.2	3.6
25	MAKAP	AD	1045.	4	-15.6	5.2	2	7.8	4.6
13	ROME.	AD	1029.	4	4.2	1.4	5	34.0	2.3
13	ROME.	DG	832.	13	3.7	2.0	13	-26.3	2.8
3	BERMU	DG	928.	28	-3.9	3.4	29	5.6	3.0
27	LA-MO	AG	931.	15	18.9	3.8	13	-7.0	2.2
11	SARDI	AD	728.	12	24.6	3.9	10	-19.9	3.4
11	SARDI	DG	917.	18	-0.1	6.3	12	-20.3	5.0
28	NORFO	DG	861.	13	3.7	5.0	12	-16.7	5.1
29	RIO-D	DG	1078.	15	-10.3	3.3	17	57.2	3.8
29	RIO-D	AG	1128.	1	-42.3	0.	1	64.2	0.
9	FARNB	AD	738.	12	18.7	4.7	13	-23.7	3.7
28	NORFO	AD	1042.	7	-21.8	1.7	6	27.6	3.1
28	NORFO	AG	1003.	6	-13.2	6.5	5	9.3	4.7
23	TANAN	AD	704.	5	13.0	1.5	1	-43.9	0.
31	BELEM	AD	959.	10	-12.7	4.4	9	18.2	5.2
31	BELEM	AG	1136.	4	-38.1	5.7	6	61.8	6.5
27	LA-MO	CG	923.	10	5.2	1.8	10	4.6	2.6
31	BELEM	AC	793.	5	-15.8	2.6	2	-52.3	2.7
31	BELEM	CD	1066.	12	3.6	2.6	12	60.4	4.4
27	LA-MO	AC	908.	3	16.6	2.5	1	-8.7	0.
27	LA-MO	CH	770.	5	9.3	7.2	2	-6.2	3.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX B

[illegible]	RIO-D	AD	931.	4	-17.4	2.9	0	0.	0.
29	RIO-D	CG	1210.	9	-20.9	2.4	8	83.3	7.7
9	FARNB	DG	885.	2	1.2	4.0	0	0.	0.
22	HESTM	CD	1036.	4	-28.6	2.3	0	0.	0.
32	NEA.M	AG	707.	5	16.6	2.0	4	-54.1	7.1
32	NEA.M	GH	901.	1	1.6	0.	1	-27.4	0.
33	SABAN	AC	840.	4	-8.3	1.9	1	-38.0	0.
33	SABAN	CD	1076.	8	-12.4	3.9	8	52.9	3.7
32	NEA.M	AH	708.	2	10.3	5.7	4	-64.8	3.5
24	PIARC	AC	832.	3	-2.4	3.0	0	0.	0.
24	PIARC	AD	1000.	3	-15.3	2.8	0	0.	0.
33	SABAN	AD	1015.	4	-24.1	5.3	4	23.1	4.0
33	SABAN	DG	1011.	6	-8.9	2.6	6	31.8	2.8
34	TSUSH	CD	808.	2	12.7	2.4	0	0.	0.
22	HESTM	DG	831.	1	48.4	0.	1	-32.9	0.
33	SABAN	AG	1127.	1	-37.6	0.	1	57.0	0.
33	SABAN	CG	1187.	1	-21.2	0.	1	87.3	0.
32	NEA.M	AD	703.	0	0.	0.	3	-38.4	5.2
36	VILAN	AD	841.	1	1.0	0.	5	-11.0	2.6
36	VILAN	AG	878.	3	-9.0	7.5	4	-11.5	0.4
36	VILAN	DG	937.	1	-4.2	0.	1	6.7	0.
25	MAKAP	DH	860.	0	0.	0.	1	-7.5	0.
35	OROTE	CD	739.	0	0.	0.	1	-14.3	0.
35	OROTE	DH	1175.	0	0.	0.	3	62.9	0.4
36	VILAN	AH	644.	0	0.	0.	2	-54.9	0.6

PHASE DIFFERENCES

DATE	SITE	LOP	DAY	NIGHT
7005	BERMU	AC	-0.015	9.999
7005	BERMU	AG	-0.081	9.999
7005	NELC,	CG	0.059	-0.242
7005	ROME,	AC	0.218	9.999
7005	ROME,	AG	0.197	9.999
7005	ROME,	CG	-0.028	0.427
7005	SARDI	AG	0.294	9.999
7005	WALES	AC	-0.027	9.999
7006	BERMU	AC	-0.039	9.999
7006	BERMU	AG	-0.082	9.999
7006	NELC,	CG	0.068	-0.292
7006	ROME,	AC	0.185	9.999
7006	ROME,	AG	0.169	9.999
7006	ROME,	CG	-0.020	9.999
7006	SARDI	AG	0.315	9.999
7006	WALES	AC	-0.020	9.999
7007	BERMU	AC	-0.050	9.999
7007	BERMU	AG	-0.092	9.999
7007	MIAMI	CG	-0.058	0.604
7007	NELC,	CG	0.061	-0.309
7007	ROME,	AC	0.177	9.999
7007	ROME,	AG	0.164	9.999
7007	ROME,	CG	-0.053	0.402
7007	SARDI	AG	0.297	9.999
7007	WALES	AC	-0.015	9.999
7008	NELC,	CG	0.053	-0.276
7008	ROME,	CG	-0.079	0.412
7009	BERMU	AG	-0.230	0.245
7009	MIAMI	CG	-0.085	0.597
7009	NELC,	CG	0.035	-0.270
7009	ROME,	AG	0.068	0.150
7010	BERMU	AG	-0.222	0.187
7010	MIAMI	CG	-0.123	0.485
7010	NELC,	CG	0.025	-0.234
7010	ROME,	AG	0.080	0.100
7010	ROME,	CG	-0.128	0.363
7011	BERMU	AG	-0.242	0.205
7011	MIAMI	AG	9.999	0.219
7011	MIAMI	CG	-0.076	0.525
7011	NELC,	CG	0.034	-0.230
7011	ROME,	AG	9.999	0.088
7011	ROME,	CG	-0.083	0.367
7012	BERMU	AC	9.999	-0.486
7012	BERMU	AG	9.999	0.242
7012	MIAMI	AG	9.999	0.275
7012	MIAMI	CG	-0.053	0.565
7012	NELC,	CG	0.053	-0.231
7012	ROME,	AC	9.999	-0.293
7012	ROME,	AG	9.999	0.101
7012	ROME,	CG	-0.057	0.398
7101	BERMU	AG	9.999	0.262
7101	BERMU	CG	-0.019	0.730
7101	CORAL	AC	9.999	-0.293
7101	CORAL	AC	9.999	-0.305
7101	CORAL	AC	9.999	-0.299
7101	FARNB	AG	9.999	-0.446
7101	GRAND	CG	0.160	-0.169
7101	MIAMI	AG	9.999	0.308
7101	MIAMI	CG	-0.037	0.549
7101	NELC,	CG	0.050	-0.293
7101	OSLO,	AG	9.999	-0.587
7101	SPITS	AG	9.999	-0.713
7101	ROME,	AG	9.999	0.105
7101	ROME,	CG	-0.038	0.363
7101	SARDI	AG	9.999	-0.429
7102	BERMU	AG	-0.252	0.188
7102	BERMU	CG	-0.071	0.773
7102	FARNB	AG	0.214	-0.506
7102	NELC,	CG	0.026	-0.269
7102	OSLO,	AG	0.213	-0.652
7102	SPITS	AG	9.999	-0.737
7102	ROME,	AG	-0.023	-0.001
7102	ROME,	CG	-0.103	0.407
7102	SARDI	AG	0.132	-0.510
7103	BERMU	AG	-0.203	0.262
7103	BERMU	CG	-0.087	0.774
7103	FARNB	AG	0.190	-0.495
7103	GRAND	CG	0.129	-0.155
7103	NELC,	CG	0.025	-0.248
7103	OSLO,	AG	0.213	-0.624
7103	ROME,	AG	0.088	0.078
7103	ROME,	CG	-0.083	0.442
7103	SARDI	AG	0.138	-0.489
7104	BERMU	AC	-0.167	9.999
7104	BERMU	AG	-0.203	0.193
7104	BERMU	CG	-0.085	0.738
7104	FARNB	AG	0.173	-0.503
7104	GRAND	CG	0.139	-0.150
7104	OSLO,	AG	0.302	-0.612
7104	SPITS	AC	0.025	9.999
7104	SPITS	AG	-0.071	9.999
7104	ROME,	AC	0.131	9.999
7104	ROME,	AG	0.062	9.999
7104	ROME,	CG	-0.077	0.413
7104	SARDI	AG	0.162	-0.412
7105	BERMU	AC	-0.074	9.999
7105	BERMU	AG	-0.134	9.999
7105	BERMU	CG	-0.064	0.703
7105	FARNB	AG	0.206	9.999
7105	GRAND	CG	0.155	-0.147
7105	MIAMI	CG	-0.074	0.566
7105	NELC,	CG	0.046	-0.291
7105	OSLO,	AG	0.217	9.999
7105	SPITS	AC	0.097	9.999
7105	SPITS	AG	-0.066	9.999
7105	ROME,	AC	0.188	9.999
7105	ROME,	AG	0.137	9.999
7105	ROME,	CG	-0.050	0.394
7105	SARDI	AG	0.177	9.999
7106	BERMU	AC	-0.040	9.999
7106	BERMU	AG	-0.105	9.999
7106	BERMU	CG	-0.072	0.734
7106	FARNB	AG	0.301	9.999
7106	NELC,	CG	0.060	-0.323
7106	OSLO,	AG	0.278	9.999
7106	SPITS	AC	0.114	9.999
7106	SPITS	AG	-0.062	9.999
7106	ROME,	AC	0.217	9.999
7106	ROME,	AG	0.156	9.999
7106	ROME,	CG	-0.060	9.999
7107	BERMU	AC	-0.043	9.999
7107	BERMU	AG	-0.108	9.999
7107	BERMU	CG	-0.074	0.754
7107	FARNB	AG	0.305	9.999
7107	NELC,	CG	0.055	-0.322
7107	OSLO,	AG	0.278	9.999
7107	SPITS	AC	0.104	9.999
7107	SPITS	AG	-0.040	9.999
7107	ROME,	AC	0.204	9.999
7107	ROME,	AG	0.165	9.999
7107	ROME,	CG	-0.055	0.417
7107	SARDI	AG	0.222	9.999
7107	TANAN	AG	0.287	9.999
7108	BERMU	AC	-0.062	9.999
7108	BERMU	AG	-0.131	9.999
7108	BERMU	CG	-0.093	0.776
7108	FARNB	AG	0.290	9.999
7108	NELC,	CG	0.051	-0.241
7108	OSLO,	AG	0.272	9.999
7108	SPITS	AC	0.133	9.999
7108	SPITS	AG	-0.041	9.999
7108	ROME,	AC	0.192	9.999
7108	ROME,	AG	0.143	9.999
7108	ROME,	CG	-0.068	0.459
7108	SARDI	AG	0.199	9.999
7108	TANAN	AG	0.276	9.999
7109	BERMU	AG	-0.206	0.260
7109	BERMU	CG	-0.113	0.769
7109	FARNB	AG	0.244	-0.436
7109	MIAMI	CG	-0.202	0.513
7109	NELC,	CG	0.035	-0.276
7109	OSLO,	AG	0.282	-0.619
7109	ROME,	AG	0.038	0.061
7109	ROME,	CG	-0.098	0.415
7109	SARDI	AG	0.161	-0.477
7109	TANAN	AG	0.295	9.999
7110	BERMU	AG	-0.292	0.233
7110	BERMU	CG	-0.137	0.671
7110	FARNB	AG	0.231	-0.455
7110	GRAND	CG	0.147	-0.142
7110	MIAMI	CG	-0.239	0.412
7110	NELC,	CG	0.050	-0.178
7110	OSLO,	AG	0.262	-0.610
7110	ROME,	AG	0.001	0.051
7110	ROME,	CG	-0.104	0.405
7110	SARDI	AG	0.152	-0.444
7110	TANAN	AG	0.178	-0.086
7111	BERMU	AG	-0.218	0.260
7111	BERMU	CG	-0.091	0.659
7111	FARNB	AG	0.184	-0.456
7111	MIAMI	CG	-0.120	0.452
7111	NELC,	CG	0.049	-0.238
7111	OSLO,	AG	0.144	-0.596
7111	RESOL	CG	9.999	-0.208
7111	ROME,	AG	9.999	0.123
7111	ROME,	CG	-0.043	0.382
7111	SARDI	AG	0.155	-0.435
7111	TANAN	AG	0.222	-0.226
7112	BERMU	AC	9.999	-0.521
7112	BERMU	AG	9.999	0.222
7112	BERMU	CG	-0.101	0.709
7112	CORAL	AC	9.999	-0.333
7112	FARNB	AG	9.999	-0.482
7112	MIAMI	CG	-0.106	0.514
7112	NELC,	CG	0.044	-0.239
7112	PYRAM	AG	9.999	-0.461
7112	RESOL	AC	9.999	-0.191
7112	ROME,	AC	9.999	-0.330
7112	ROME,	AG	9.999	0.053
7112	ROME,	CG	-0.064	0.404
7112	SARDI	AG	9.999	-0.423
7112	TANAN	AG	9.999	-0.238
7201	BERMU	AG	9.999	0.207
7201	BERMU	CG	-0.032	0.706
7201	NELC,	CG	0.043	-0.286
7201	RESOL	CG	9.999	[illegible]

APPENDIX B

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7201	ROME,	AG	9.999	0.062	7212	BERMU	AD	9.999	0.107	7307	TANAN	AG	0.090	9.999
7201	ROME,	CG	-0.098	0.382	7212	MAKAP	AD	9.999	0.110	7308	BERMU	DG	0.009	0.061
7201	SARDI	AG	9.999	-0.475	7212	MAKAP	AG	9.999	-0.382	7308	ROME,	DG	0.051	-0.222
7201	TANAN	AG	9.999	-0.255	7212	MAKAP	DG	-0.014	-0.517	7309	BERMU	DG	-0.047	0.061
7202	MONTG	CG	9.999	0.350	7212	PIARC	CD	-0.032	0.518	7309	NORFO	DG	0.028	-0.158
7202	NELC,	CG	0.054	-0.282	7212	ROME,	AD	9.999	0.350	7309	RIO-D	DG	-0.150	0.544
7202	RESOL	AG	9.999	-0.417	7212	ROME,	DG	0.037	-0.230	7309	ROME,	DG	0.036	-0.280
7202	RESOL	CG	-0.113	-0.273	7301	MAKAP	DG	-0.025	-0.613	7310	BERMU	DG	-0.054	0.050
7202	ROME,	AG	-0.028	0.089	7301	ROME,	AD	9.999	0.366	7310	NORFO	DG	0.032	-0.164
7202	ROME,	CG	-0.090	0.389	7301	ROME,	DG	0.029	-0.294	7310	RIO-D	AD	9.999	0.140
7202	SARDI	AG	0.167	-0.470	7301	TANAN	AG	9.999	-0.271	7310	RIO-D	AG	-0.423	0.642
7202	TANAN	AG	0.198	9.999	7302	BERMU	AD	9.999	0.137	7310	RIO-D	DG	-0.150	0.513
7203	MONTG	CG	-0.094	0.356	7302	BERMU	AG	-0.295	0.215	7310	ROME,	DG	0.038	-0.258
7203	ROME,	AG	0.091	0.060	7302	BERMU	DG	-0.068	0.043	7311	BERMU	DG	-0.033	0.044
7203	ROME,	CG	-0.095	0.416	7302	PIARC	CD	-0.063	0.506	7311	NORFO	DG	0.029	-0.155
7203	SARDI	AG	0.176	-0.473	7302	ROME,	AD	9.999	0.305	7311	RIO-D	DG	-0.128	0.511
7203	TANAN	AG	0.300	9.999	7302	ROME,	DG	0.018	-0.275	7311	ROME,	DG	0.041	-0.246
7204	BERMU	AG	-0.195	0.210	7302	TANAN	AG	0.226	-0.135	7312	BERMU	AG	9.999	0.149
7204	BERMU	CG	-0.084	0.704	7303	BERMU	AD	-0.202	0.140	7312	BERMU	DG	-0.064	0.041
7204	CORAL	AC	0.205	9.999	7303	BERMU	AG	-0.244	0.201	7312	LA-MO	AG	9.999	-0.037
7204	MAKAP	AG	0.069	9.999	7303	BERMU	DG	-0.050	0.053	7312	NORFO	DG	-0.002	-0.193
7204	MONTG	CG	-0.025	0.380	7303	LA-MO	AG	0.279	-0.089	7312	RIO-D	DG	-0.146	0.527
7204	NELC,	CG	0.033	-0.264	7303	ROME,	AD	0.029	0.347	7312	ROME,	AD	9.999	0.334
7204	ROME,	AC	0.162	9.999	7303	ROME,	AG	0.031	0.035	7312	ROME,	AG	9.999	0.027
7204	ROME,	AG	0.108	9.999	7303	ROME,	DG	-0.011	-0.305	7312	ROME,	DG	0.046	-0.252
7204	ROME,	CG	-0.084	0.410	7303	SARDI	AD	0.317	-0.201	7312	SARDI	AD	9.999	-0.234
7204	TANAN	AG	0.274	-0.166	7303	SARDI	AG	0.229	-0.419	7312	SARDI	AG	9.999	-0.361
7205	BERMU	AC	-0.061	9.999	7303	SARDI	DG	-0.086	-0.305	7312	SARDI	DG	9.999	-0.136
7205	BERMU	AG	-0.152	9.999	7303	TANAN	AG	9.999	-0.069	7401	BERMU	AD	9.999	0.152
7205	BERMU	CG	-0.104	0.661	7304	BERMU	AD	-0.259	9.999	7401	BERMU	AG	9.999	0.195
7205	MAKAP	AG	-0.017	9.999	7304	BERMU	AG	-0.280	0.133	7401	BERMU	DG	-0.067	0.028
7205	MONTG	CG	-0.055	0.319	7304	BERMU	DG	-0.042	0.063	7401	FARNB	AD	9.999	-0.310
7205	NELC,	CG	0.037	-0.310	7304	ROME,	DG	0.020	-0.307	7401	FARNB	AG	9.999	-0.516
7205	ROME,	AC	0.214	9.999	7304	SARDI	DG	-0.029	9.999	7401	LA-MO	AG	9.999	-0.064
7205	TANAN	AG	0.273	9.999	7305	BERMU	AD	-0.207	9.999	7401	NORFO	AD	9.999	0.256
7206	BERMU	AC	-0.078	9.999	7305	BERMU	AG	-0.216	9.999	7401	NORFO	AG	9.999	0.139
7206	BERMU	AG	-0.178	9.999	7305	BERMU	DG	-0.013	0.076	7401	NORFO	DG	-0.057	-0.269
7206	BERMU	CG	-0.112	0.672	7305	LA-MO	AG	0.212	9.999	7401	RIO-D	DG	-0.122	0.566
7206	MAKAP	AG	-0.080	9.999	7305	NORFO	DG	0.032	-0.129	7401	SARDI	AD	9.999	-0.236
7206	MONTG	CG	-0.064	0.340	7305	ROME,	AD	0.057	9.999	7401	SARDI	AG	9.999	-0.382
7206	NELC,	CG	0.039	-0.372	7305	ROME,	AG	0.092	9.999	7401	SARDI	DG	9.999	-0.179
7206	ROME,	AC	0.152	9.999	7305	ROME,	DG	0.046	-0.242	7402	BERMU	AD	9.999	0.111
7206	ROME,	AG	0.086	9.999	7305	SARDI	AD	0.220	9.999	7402	BERMU	AG	-0.330	0.150
7206	ROME,	CG	-0.091	9.999	7305	SARDI	AG	0.243	9.999	7402	BERMU	DG	-0.022	0.033
7206	TANAN	AG	0.317	9.999	7305	SARDI	DG	0.021	9.999	7402	FARNB	AD	9.999	-0.265
7207	BERMU	AC	-0.065	9.999	7305	TANAN	AG	0.154	9.999	7402	FARNB	AG	0.177	-0.514
7207	BERMU	AG	-0.155	9.999	7306	BERMU	AD	-0.210	9.999	7402	LA-MO	AG	9.999	-0.066
7207	BERMU	CG	-0.107	0.703	7306	BERMU	AG	-0.190	9.999	7402	NORFO	AD	9.999	0.255
7207	NELC,	CG	0.045	-0.355	7306	BERMU	DG	0.005	0.088	7402	NORFO	AG	-0.244	0.107
7207	ROME,	AC	0.187	9.999	7306	NORFO	DG	0.070	-0.131	7402	NORFO	DG	-0.030	-0.249
7207	ROME,	AG	0.113	9.999	7306	ROME,	AD	0.032	9.999	7402	SARDI	AD	9.999	-0.232
7207	ROME,	CG	-0.101	0.373	7306	ROME,	AG	0.108	9.999	7402	SARDI	AG	0.248	-0.377
7208	NELC,	CG	0.049	-0.292	7306	ROME,	DG	0.070	-0.268	7402	SARDI	DG	-0.055	-0.136
7208	ROME,	AG	0.105	9.999	7306	SARDI	AD	0.212	9.999	7402	TANAN	AG	0.133	-0.320
7208	ROME,	CG	9.999	0.582	7306	SARDI	AG	0.262	9.999	7403	BERMU	AD	-0.063	0.253
7208	TANAN	AG	0.247	9.999	7306	SARDI	DG	0.040	9.999	7403	BERMU	AG	-0.359	0.131
7209	ROME,	AG	0.077	0.149	7306	TANAN	AG	0.134	9.999	7403	FARNB	AD	0.207	-0.240
7209	ROME,	CG	-0.101	0.488	7307	BERMU	AD	-0.201	9.999	7403	FARNB	AG	0.167	-0.514
7209	TANAN	AG	0.214	-0.132	7307	BERMU	AG	-0.184	9.999	7403	LA-MO	AG	0.124	-0.087
7210	NELC,	CG	0.018	-0.269	7307	BERMU	DG	-0.005	0.067	7403	NORFO	AD	-0.213	0.259
7210	TANAN	AG	0.222	-0.077	7307	LA-MO	AG	0.180	9.999	7403	NORFO	AG	-0.121	0.131
7211	BERMU	AD	9.999	-0.073	7307	NORFO	DG	0.057	-0.145	7403	NORFO	DG	0.018	-0.195
7211	FARNB	AG	0.193	-0.458	7307	RIO-D	DG	-0.136	0.521	7403	SARDI	AD	9.999	-0.208
7211	MAKAP	DG	0.173	-0.500	7307	ROME,	AD	0.050	9.999	7403	SARDI	AG	0.253	-0.380
7211	NELC,	CG	0.018	-0.284	7307	ROME,	AG	0.104	9.999	7403	SARDI	DG	9.999	-0.179
7211	PIARC	CD	-0.077	0.500	7307	ROME,	DG	0.056	-0.238	7403	TANAN	AG	0.132	-0.286

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7404	BERMU	AD	-0.179	9.999	7408	SARDI	AD	0.204	9.999	7501	RIO-D	DG	9.999	0.597
7404	BERMU	AG	-0.355	0.068	7408	SARDI	AG	0.272	9.999	7501	SARDI	AD	9.999	-0.214
7404	BERMU	DG	9.999	0.126	7408	SARDI	DG	0.059	9.999	7501	SARDI	AG	9.999	-0.425
7404	FARNB	AD	0.194	9.999	7408	TANAN	AD	0.115	9.999	7501	SARDI	DG	9.999	-0.213
7404	FARNB	AG	0.158	-0.495	7408	TANAN	AG	0.071	9.999	7501	TANAN	AG	9.999	-0.298
7404	LA-MO	AG	0.134	9.999	7409	BELEM	AG	9.999	0.626	7501	TELEC	DG	0.057	-0.532
7404	NORFO	AD	-0.248	9.999	7409	BERMU	DG	-0.107	0.033	7502	BELEM	AD	9.999	0.158
7404	NORFO	AG	-0.148	9.999	7409	FARNB	AG	9.999	-0.487	7502	BELEM	CD	0.064	0.574
7404	NORFO	DG	0.093	-0.109	7409	NORFO	AG	9.999	0.032	7502	BERMU	AD	9.999	0.055
7404	SARDI	AD	0.250	9.999	7409	SARDI	AG	9.999	-0.384	7502	BERMU	AG	-0.313	0.174
7404	SARDI	AG	0.233	-0.377	7409	SARDI	DG	9.999	-0.247	7502	BERMU	DG	-0.001	0.099
7404	SARDI	DG	-0.037	9.999	7409	TANAN	AG	9.999	-0.242	7502	FARNB	AD	9.999	-0.232
7404	TANAN	AD	0.122	9.999	7410	BELEM	AD	-0.200	0.175	7502	FARNB	AG	0.203	-0.495
7404	TANAN	AG	0.097	-0.199	7410	BELEM	AG	-0.425	0.561	7502	LA-MO	AG	9.999	-0.085
7405	BERMU	AD	-0.213	9.999	7410	BERMU	AD	-0.242	0.064	7502	LA-MO	CG	0.071	0.081
7405	BERMU	AG	-0.220	9.999	7410	BERMU	DG	-0.076	0.023	7502	MAKAP	DG	0.078	-0.406
7405	BERMU	DG	-0.007	0.098	7410	FARNB	AD	0.311	-0.220	7502	SARDI	AD	9.999	-0.173
7405	FARNB	AD	0.172	9.999	7410	FARNB	AG	0.200	-0.491	7502	SARDI	AG	0.229	-0.397
7405	FARNB	AG	0.191	9.999	7410	LA-MO	AG	0.148	-0.045	7502	SARDI	DG	-0.120	-0.222
7405	LA-MO	AG	0.178	9.999	7410	NORFO	AD	-0.233	0.295	7502	TANAN	AG	0.116	-0.161
7405	NORFO	AD	-0.202	9.999	7410	NORFO	AG	-0.138	0.056	7502	TELEC	DG	0.114	-0.466
7405	NORFO	AG	-0.078	9.999	7410	SARDI	AD	0.317	-0.146	7503	BELEM	AD	-0.092	0.291
7405	NORFO	DG	0.106	-0.106	7410	SARDI	AG	0.241	-0.385	7503	BELEM	CD	0.064	0.629
7405	SARDI	AD	0.245	9.999	7410	SARDI	DG	-0.119	-0.220	7503	BERMU	AG	-0.269	0.173
7405	SARDI	AG	0.259	9.999	7410	TANAN	AG	0.027	-0.142	7503	BERMU	DG	-0.003	0.084
7405	SARDI	DG	0.012	9.999	7411	BELEM	AD	9.999	0.120	7503	LA-MO	AG	0.196	-0.082
7405	TANAN	AD	0.151	9.999	7411	BELEM	AG	-0.431	0.538	7503	LA-MO	CG	0.073	0.062
7405	TANAN	AG	0.076	9.999	7411	BERMU	AD	9.999	0.092	7503	LA-MO	CH	0.218	9.999
7405	TELEC	DG	0.104	-0.502	7411	BERMU	AG	9.999	0.114	7503	MAKAP	DG	0.032	-0.470
7406	BELEM	AD	-0.126	9.999	7411	BERMU	DG	-0.075	0.017	7503	NORFO	AD	-0.219	0.332
7406	BELEM	AG	-0.313	0.684	7411	FARNB	AD	9.999	-0.240	7503	RIO-D	AD	-0.137	9.999
7406	BERMU	AD	-0.207	9.999	7411	FARNB	AG	0.146	-0.479	7503	RIO-D	CG	-0.200	9.999
7406	BERMU	AG	-0.178	9.999	7411	LA-MO	AG	9.999	-0.031	7503	RIO-D	DG	-0.079	0.586
7406	BERMU	DG	0.012	0.111	7411	LA-MO	CG	0.063	0.047	7503	SARDI	AD	0.268	-0.203
7406	FARNB	AD	0.179	9.999	7411	NORFO	AD	9.999	0.261	7503	SARDI	AG	0.250	-0.409
7406	FARNB	AG	0.229	9.999	7411	RIO-D	DG	-0.092	0.548	7503	SARDI	DG	-0.052	-0.230
7406	LA-MO	AG	0.190	9.999	7411	SARDI	AD	9.999	-0.147	7503	TANAN	AG	0.142	-0.219
7406	NORFO	AD	-0.206	9.999	7411	SARDI	AG	0.253	-0.319	7503	TELEC	DG	0.217	-0.376
7406	NORFO	AG	-0.060	9.999	7411	SARDI	DG	9.999	-0.147	7504	BELEM	AC	-0.184	9.999
7406	NORFO	DG	0.108	9.999	7411	TELEC	DG	0.108	-0.463	7504	BELEM	AD	-0.117	9.999
7406	SARDI	AD	0.213	9.999	7412	BELEM	AC	9.999	-0.542	7504	BELEM	CD	0.022	0.592
7406	SARDI	AG	0.276	9.999	7412	BELEM	AD	9.999	0.116	7504	BERMU	AC	-0.194	9.999
7406	SARDI	DG	0.051	9.999	7412	BELEM	AG	9.999	0.598	7504	BERMU	AD	-0.251	9.999
7406	TANAN	AD	0.141	9.999	7412	BELEM	CD	0.042	0.601	7504	BERMU	AG	-0.242	0.189
7406	TANAN	AG	0.086	9.999	7412	BERMU	AC	9.999	-0.557	7504	BERMU	DG	-0.031	0.051
7407	BERMU	AD	-0.239	9.999	7412	BERMU	AD	9.999	0.124	7504	FARNB	AD	0.198	9.999
7407	BERMU	AG	-0.237	9.999	7412	BERMU	AG	9.999	0.124	7504	FARNB	AG	0.189	-0.463
7407	BERMU	DG	-0.009	0.081	7412	BERMU	DG	-0.092	0.011	7504	FARNB	DG	-0.017	9.999
7407	FARNB	AD	0.146	9.999	7412	FARNB	AD	9.999	-0.245	7504	HESTM	CD	-0.253	9.999
7407	FARNB	AG	0.236	9.999	7412	FARNB	AG	9.999	-0.524	7504	LA-MO	CG	0.040	0.040
7407	LA-MO	AG	0.193	9.999	7412	LA-MO	AC	9.999	-0.087	7504	MAKAP	AG	0.035	9.999
7407	SARDI	AD	0.206	9.999	7412	LA-MO	AG	9.999	-0.106	7504	RIO-D	AD	-0.167	9.999
7407	SARDI	AG	0.288	9.999	7412	LA-MO	CG	0.045	-0.001	7504	RIO-D	CG	-0.178	0.777
7407	SARDI	DG	0.062	9.999	7412	MAKAP	AD	9.999	0.045	7504	RIO-D	DG	-0.067	0.587
7407	TANAN	AD	0.120	9.999	7412	MAKAP	AG	9.999	-0.474	7504	SARDI	AD	0.237	9.999
7407	TANAN	AG	0.096	9.999	7412	SARDI	AG	9.999	-0.395	7504	SARDI	DG	0.034	9.999
7408	BELEM	AD	-0.196	9.999	7412	SARDI	DG	9.999	-0.221	7504	TANAN	AG	0.114	-0.093
7408	BELEM	AG	-0.353	0.700	7412	TANAN	AD	9.999	-0.439	7504	TELEC	CD	-0.021	0.481
7408	BERMU	AD	-0.339	9.999	7412	TANAN	AG	9.999	-0.295	7505	BELEM	AC	-0.152	9.999
7408	BERMU	AG	-0.231	9.999	7412	TELEC	DG	0.119	-0.517	7505	BELEM	AD	-0.110	9.999
7408	BERMU	DG	0.001	0.054	7501	BELEM	AD	9.999	0.201	7505	BELEM	CD	-0.004	0.584
7408	FARNB	AD	0.113	9.999	7501	BELEM	CD	0.074	0.612	7505	BERMU	AC	-0.049	9.999
7408	FARNB	AG	0.229	9.999	7501	BERMU	AD	9.999	0.105	7505	BERMU	AD	-0.199	9.999
7408	LA-MO	AG	0.167	9.999	7501	BERMU	AG	9.999	0.145	7505	BERMU	DG	-0.071	0.023
7408	NORFO	AD	-0.208	9.999	7501	BERMU	DG	-0.078	0.025	7505	FARNB	AD	0.158	9.999
7408	RIO-D	DG	-0.065	0.623	7501	LA-MO	AG	9.999	-0.087	7505	FARNB	AG	0.192	9.999

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7505	FARNB	DG	0.040	9.999
7505	HESTM	CD	-0.291	9.999
7505	LA-MO	CH	0.064	9.999
7505	MAKAP	AD	-0.138	9.999
7505	MAKAP	AG	-0.063	9.999
7505	MAKAP	DG	0.041	-0.489
7505	NEA,M	AG	0.175	9.999
7505	NEA,M	GH	0.016	9.999
7505	RIO-D	AD	-0.199	9.999
7505	RIO-D	CG	-0.203	0.919
7505	RIO-D	DG	9.999	0.606
7505	SABAN	AC	-0.085	9.999
7505	SABAN	CD	-0.160	0.510
7505	SARDI	AD	0.258	9.999
7505	SARDI	AG	0.276	9.999
7505	SARDI	DG	0.051	9.999
7505	TANAN	AG	0.115	9.999
7505	TELEC	CD	-0.055	0.477
7506	BELEM	AC	-0.142	9.999
7506	BELEM	AD	-0.101	9.999
7506	BELEM	CD	-0.008	0.621
7506	BERMU	AC	-0.047	9.999
7506	BERMU	AG	-0.164	9.999
7506	FARNB	AD	0.178	9.999
7506	FARNB	AG	0.231	9.999
7506	HESTM	CD	-0.305	9.999
7506	LA-MO	AC	0.179	9.999
7506	LA-MO	AG	0.201	9.999
7506	LA-MO	CG	0.020	0.022
7506	LA-MO	CH	0.033	9.999
7506	MAKAP	AD	-0.155	9.999
7506	MAKAP	AG	-0.075	9.999
7506	MAKAP	DG	0.082	-0.532
7506	NEA,M	AG	0.191	9.999
7506	NEA,M	AH	0.144	9.999
7506	PIARC	AC	-0.019	9.999
7506	PIARC	AD	-0.166	9.999
7506	PIARC	CD	-0.144	0.512
7506	RIO-D	AD	-0.195	9.999
7506	RIO-D	CG	-0.215	0.798
7506	RIO-D	DG	-0.058	0.621
7506	SABAN	AC	-0.079	9.999
7506	SABAN	AD	-0.229	9.999
7506	SABAN	CD	-0.170	0.535
7506	SABAN	DG	-0.062	0.330
7506	SARDI	AG	0.280	9.999
7506	SARDI	DG	0.054	9.999
7506	TELEC	CD	-0.092	0.464
7507	BELEM	AC	-0.127	9.999
7507	BELEM	AD	-0.066	9.999
7507	BELEM	CD	0.023	0.688
7507	BERMU	DG	-0.043	0.048
7507	FARNB	AD	0.195	9.999
7507	FARNB	AG	0.247	9.999
7507	HESTM	CD	-0.296	9.999
7507	LA-MO	AC	0.181	9.999
7507	LA-MO	AG	0.217	9.999
7507	LA-MO	CG	0.044	0.035
7507	LA-MO	CH	0.075	9.999
7507	MAKAP	AD	-0.104	9.999
7507	MAKAP	DG	0.011	-0.567
7507	PIARC	AC	0.004	9.999
7507	PIARC	AD	-0.121	9.999
7507	PIARC	CD	-0.113	0.587
7507	RIO-D	CG	-0.220	0.931
7507	RIO-D	DG	-0.076	0.615

7507	SABAN	AC	-0.061	9.999
7507	SABAN	AD	-0.192	9.999
7507	SABAN	CD	-0.147	0.584
7507	SABAN	DG	-0.085	0.313
7507	SARDI	DG	0.051	9.999
7507	TELEC	CD	-0.059	0.513
7507	TSUSH	CD	0.110	9.999
7508	BELEM	AC	-0.185	9.999
7508	BELEM	AD	-0.107	9.999
7508	BELEM	CD	0.019	0.597
7508	BERMU	AC	-0.016	9.999
7508	BERMU	AD	-0.201	9.999
7508	BERMU	AG	-0.150	9.999
7508	BERMU	DG	-0.057	0.021
7508	FARNB	AD	0.191	9.999
7508	FARNB	AG	0.210	9.999
7508	HESTM	CG	0.078	9.999
7508	HESTM	DG	0.484	9.999
7508	LA-MO	AC	0.137	9.999
7508	LA-MO	AG	0.183	9.999
7508	LA-MO	CG	0.033	0.059
7508	LA-MO	CH	0.074	9.999
7508	MAKAP	AD	-0.227	9.999
7508	MAKAP	DG	0.015	-0.438
7508	PIARC	AC	-0.056	9.999
7508	PIARC	AD	-0.173	9.999
7508	PIARC	CD	-0.114	0.522
7508	RIO-D	CG	-0.238	0.884
7508	RIO-D	DG	-0.098	0.599
7508	SABAN	AC	-0.107	9.999
7508	SABAN	AD	-0.225	9.999
7508	SABAN	CD	-0.145	0.557
7508	SABAN	DG	-0.085	0.346
7508	SARDI	DG	0.050	9.999
7508	TELEC	CD	-0.069	0.451
7508	TELEC	DG	0.243	-0.328
7508	TSUSH	CD	0.144	9.999
7509	BERMU	AG	-0.218	0.224
7509	FARNB	AG	0.197	-0.489
7509	NEA,M	AG	0.143	-0.628
7509	NEA,M	AH	0.063	9.999
7509	RIO-D	CG	-0.241	0.716
7509	SABAN	AG	-0.376	0.570
7509	SABAN	CG	-0.212	0.873
7510	BELEM	AD	-0.151	0.207
7510	BELEM	CD	0.037	0.559
7510	FARNB	AD	9.999	-0.281
7510	FARNB	AG	0.189	-0.490
7510	LA-MO	AG	0.227	-0.066
7510	LA-MO	CG	0.067	0.081
7510	LA-MO	CH	9.999	-0.035
7510	NEA,M	AD	9.999	-0.441
7510	NEA,M	AG	0.173	-0.570
7510	NEA,M	AH	9.999	-0.674
7510	PIARC	CD	-0.082	0.491
7510	RIO-D	CG	-0.172	0.781
7510	RIO-D	DG	-0.093	0.587
7510	SABAN	AD	-0.317	0.231
7510	SABAN	CD	-0.127	0.497
7510	SABAN	DG	-0.075	0.338
7510	TANAN	AG	0.021	0.046
7510	VILAN	AD	0.010	-0.150
7510	VILAN	AG	-0.022	-0.111
7510	VILAN	DG	-0.042	0.067
7511	BELEM	AD	9.999	0.176
7511	BELEM	CD	0.053	0.527

7511	FARNB	AD	9.999	-0.216
7511	FARNB	AG	0.152	-0.484
7511	HESTM	DG	9.999	-0.329
7511	LA-MO	AG	9.999	-0.059
7511	LA-MO	CG	0.067	0.037
7511	LA-MO	CH	9.999	-0.089
7511	MAKAP	DG	9.999	-0.416
7511	MAKAP	DH	9.999	-0.075
7511	NEA,M	AD	9.999	-0.338
7511	NEA,M	AG	0.147	-0.488
7511	NEA,M	AH	9.999	-0.620
7511	OROTE	CD	9.999	-0.143
7511	PIARC	CD	-0.075	0.460
7511	RIO-D	CG	-0.218	0.861
7511	RIO-D	DG	-0.085	0.575
7511	SABAN	AD	9.999	0.177
7511	SABAN	CD	-0.106	0.465
7511	SABAN	DG	-0.085	0.316
7511	VILAN	AD	9.999	-0.111
7511	VILAN	AG	-0.078	-0.120
7512	BELEM	AC	9.999	-0.504
7512	BELEM	AD	9.999	0.192
7512	BELEM	CD	0.049	0.667
7512	FARNB	AD	9.999	-0.210
7512	FARNB	AG	9.999	-0.455
7512	NEA,M	AD	9.999	-0.373
7512	NEA,M	AG	9.999	-0.479
7512	NEA,M	AH	9.999	-0.616
7512	NEA,M	GH	9.999	-0.274
7512	OROTE	DH	9.999	0.633
7512	SABAN	AC	9.999	-0.380
7512	SABAN	AD	9.999	0.242
7512	SABAN	CD	-0.074	0.539
7512	SABAN	DG	-0.139	0.268
7512	VILAN	AD	9.999	-0.114
7512	VILAN	AG	9.999	-0.115
7512	VILAN	AH	9.999	-0.553
7601	FARNB	AD	9.999	-0.250
7601	FARNB	AG	0.097	-0.446
7601	OROTE	DH	9.999	0.629
7601	SABAN	AD	9.999	0.274
7601	SABAN	CD	-0.064	0.549
7601	VILAN	AD	9.999	-0.093
7601	VILAN	AG	-0.171	-0.115
7601	VILAN	AH	9.999	-0.545
7602	FARNB	AD	9.999	-0.214
7602	NEA,M	AH	9.999	-0.684
7602	OROTE	DH	9.999	0.626
7602	VILAN	AD	9.999	-0.081
7603	FARNB	AD	9.999	-0.160

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APPENDIX C

Judgmental Deletions

CODES: (1) many outages
(2) large % error

site	LOP	dates	remarks
BERMU	AC	8/72	flat data
	AG	2,3/72	flat data (no diurnal)
		11,12/73; 1/73	2 + paucity of data
	CG	2,3/72; 1,2/73	1 + 2
	DG	3/74	
HESTM	CD	12/72	2
LA-MO	AG	8/73	1
MIAMI	CG	7/71	1
NORFO	AG	3/75	1 + 2
RIO-D	AD	12/73; 1,12/74	2 + station A through
	AG	12/73; 1/74	modal degeneracy zone at night
ROME	AD	11/72	2 + many PCA's
TANAN	AG	1,4,5/71; 7/72	1 + 2
TELEC	CG	1-8/75	1 + 2
TSUSH	AH	10/75	1 + 2

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APPENDIX D

Single Station Paths, Predicted Residual Errors

site	LOP	new coefficients day	new coefficients night	old coefficients day	old coefficients night
HESTM	C	–3.2	–20.4[1]	8.7	3.2
	D	2.4	14.2	10.9	27.6
	G	7.0	–0.3	11.9	10.6
	H	–	14.0	–	27.2
MAKAP	A	–1.0	14.1[2]	–12.0	–7.7
	D	–2.4	–7.4	0.0	2.4
	H	–2.2	1.7	–2.9	2.0
PIARC	A	–5.0	6.9	–12.9	–5.2
	C	–1.3	4.5	–1.2	2.3
	D	–5.5	2.0	5.7	–5.9
LA-MO	A	–1.1	–6.6	–10.2	–10.7
	C	0.5	4.4	0.5	–4.1
	G	2.8	–7.2	4.5	2.5
	H	–5.3	6.4	7.2	22.5
TSUSH	A	–10.8	–9.8	–11.1	–21.4
	C	9.5	–	2.9	–
	D	5.9	1.7	–9.3	–16.1

1. night path only in month of Dec. (data for 1970, 71, 72, 74)
2. night path only in month of Dec. (data for 1972, 74)

(50)

APPENDIX E

Transmitter Coordinates*

station	latitude	longitude
A	66° 25′ 15.00″ N	13° 09′ 10.00″ E
B	6° 18′ 19.39″ N	10° 39′ 44.21″ W
C	21° 24′ 20.67″ N	157° 49′ 47.75″ W
D	46° 21′ 57.20″ N	98° 20′ 08.77″ W
E	20° 58′ 26.47″ S	55° 17′ 24.25″ E
F	43° 03′ 12.53″ S	65° 11′ 27.29″ W
G	10° 42′ 06.2″ N	61° 38′ 20.3″ W
H	34° 36′ 53.26″ N	129° 27′ 12.49″ E

*Mercury datum (1960)

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52X
all
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DATE

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